VOLUME XII MARCH, 1929 NUMBER 2

JOURNAL OF DAIRY SCIENCE

OFFICIAL ORGAN OF THE
AMERICAN DAIRY SCIENCE ASSOCIATION

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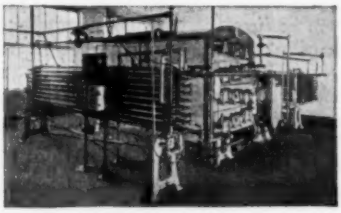

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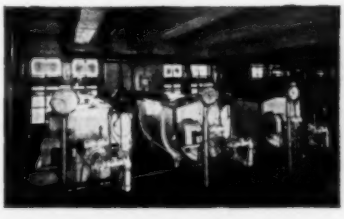

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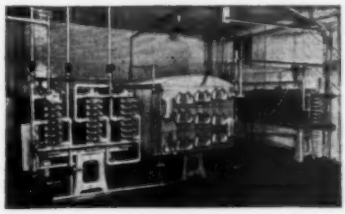

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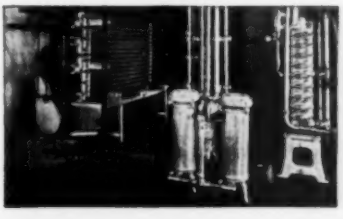

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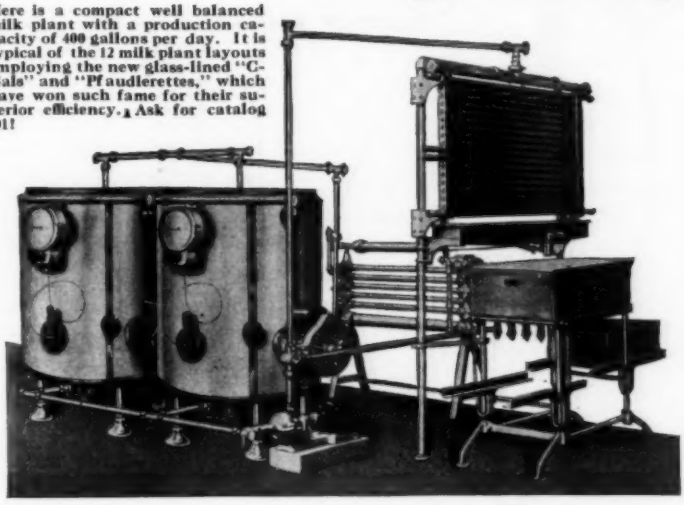

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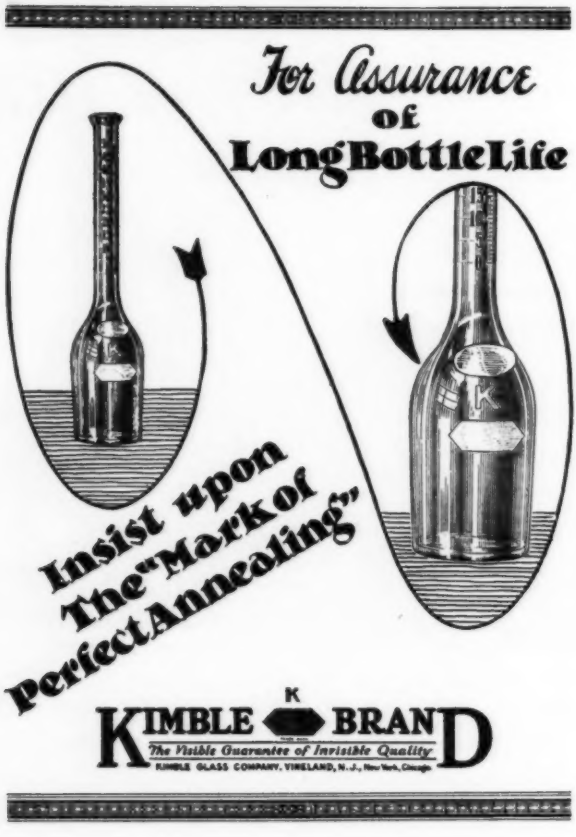

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THE APPLICATION OF STEAM FOR HEATING AND STERILIZING DAIRY EQUIPMENT*

A. W. FARRALL

Department of Agricultural Engineering, University of California, Davis

Steam is quite commonly used for heating and sterilizing dairy equipment, both on the farm and in the dairy manufacturing plant. It is used in the small self contained oil or electric sterilizers and in large continuous can washers. Bacteriologists tell us that a certain temperature maintained for a certain length of time is effective in killing bacteria. It is the problem then of the engineer to determine the best methods of applying steam to the utensils in order to heat them most thoroughly, quickly and economically. A study of this problem has been made at the University of California, by the author in coöperation between the Divisions of Dairy Industry and Agricultural Engineering. Many tests have been conducted with the small dairy farm sterilizer, with large continuous can washers in plants and with a special testing apparatus for determining the rate of heating of 10-gallon milk cans over steam jets. Most of the data presented in this discussion were obtained with the last named apparatus. It may also be stated that this is in the nature of a progress report only, since there are several phases of the problem which have not been attacked as yet. It is believed however that since the data in this paper are more or less fundamental to the whole subject, it should be called to the attention of the industry at this time.

In outlining the problem, one might consider:

First, the thermal properties of steam, and the fundamentals of heat transfer from steam to metal surfaces and from metal surfaces to air, which are involved in the study.

Second, practical applications, such as the steaming in tank

* Received for publication August 20, 1928. Presented at the meeting of The American Dairy Science Association, Madison, Wisconsin, June 27, 1928.

type sterilizers in which the utensil is surrounded on all sides both inside and out with the heating medium, or the case of the utensil being steamed over a jet in which the outside of the can may be in contact with air or steam depending upon conditions and whether it is steamed in a continuous washer or a simple can steamer.

Third, the matter of moisture left on the utensil after steaming, since any moisture left in the finished can may cause rusting of metal surfaces and growth of bacteria.

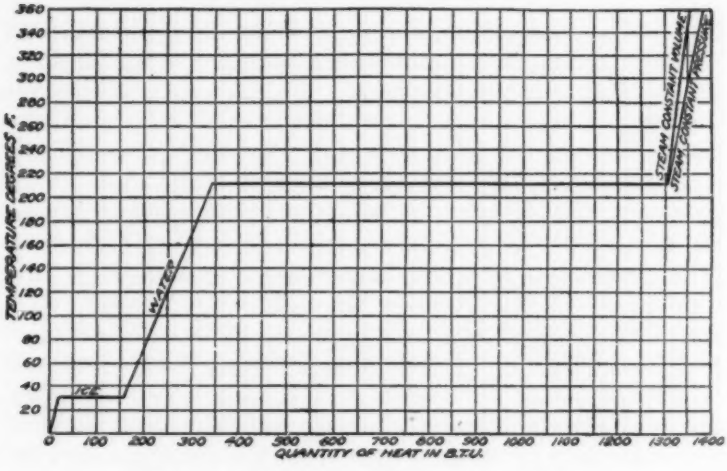

FIG. 1. HEAT-TEMPERATURE DIAGRAM FOR WATER

(From U. S. D. A. Bulletin No. 98)

THE PROPERTIES OF STEAM WHICH ARE OF IMPORTANCE IN THE STEAMING OF DAIRY UTENSILS

A study of the heating of dairy utensils would be incomplete without some discussion of the properties of the heating medium used, and therefore some of the more important thermal properties of steam are mentioned as follows:

The heat-temperature diagram (fig. 1) for water shows that considerable quantities of heat are absorbed as the water changes

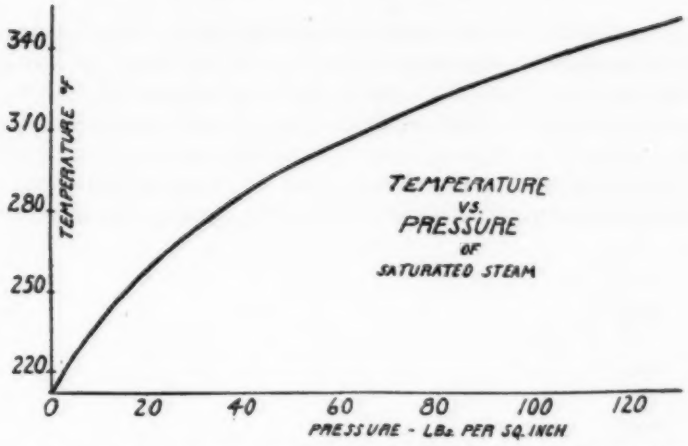

FIG. 2. CHART SHOWING HOW THE TEMPERATURE OF SATURATED STEAM VARIES WITH THE PRESSURE
(From Bureau of Standards Table)

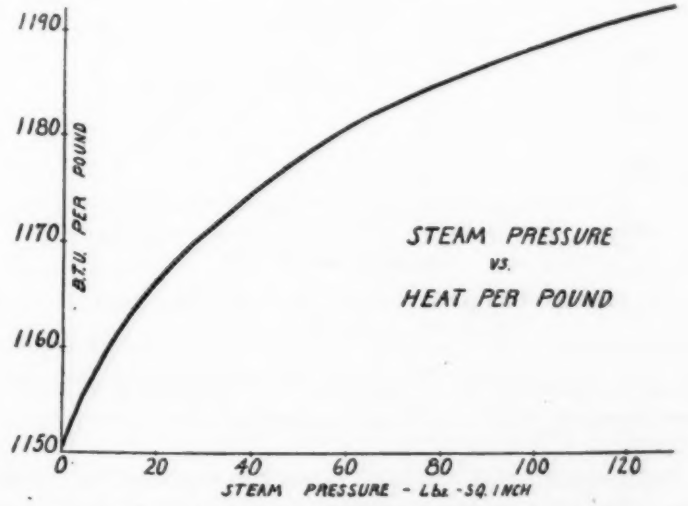

FIG. 3. CHART SHOWING HOW THE TOTAL HEAT IN A POUND OF SATURATED STEAM VARIES WITH THE PRESSURE
(From Bureau of Standard Table)

to steam, at the temperature of the boiling point. This heat is all given up again as the steam condenses and changes back to its original state. It should be mentioned that because this condensing temperature is high, and the quantity of heat liberated is great, steam is an especially desirable heating agent.

Another point worthy of note is that the temperature of saturated steam varies with the pressure. (See fig. 2.) This saturated

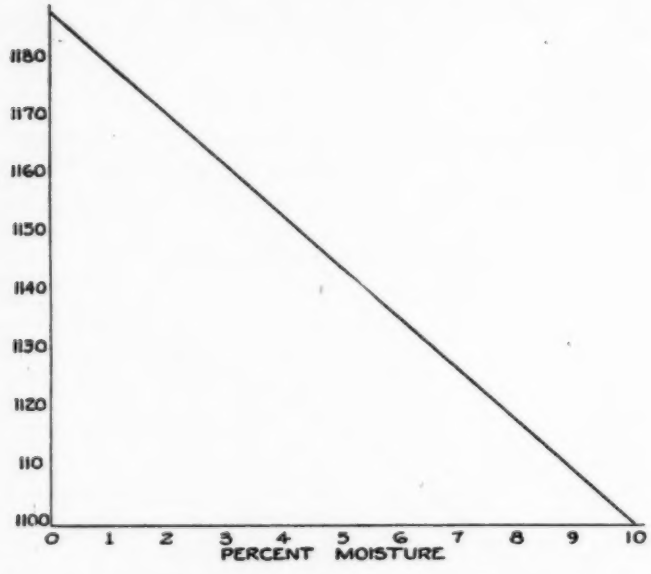

FIG. 4. CHART SHOWING THE RELATIONSHIP OF THE HEAT CARRYING CAPACITY OF STEAM WITH ITS MOISTURE CONTENT

steam at atmospheric pressure has a temperature of 212°F. approximately, while at 100 pounds pressure, the temperature is 337.9°F.

The heat content of saturated steam also varies with the pressure. The steam at high pressure carries slightly more heat per pound than it does at low pressure. (See fig. 3.)

The heat carrying capacity of steam is also dependent upon the

quality, thus saturated steam which carries 1186 B.t.u. per pound at a certain pressure and temperature carries only 1100 B.t.u. when it contains 10 per cent moisture. (See fig. 4.) The same steam if superheated 90°F. would carry approximately 1228 B.t.u. per pound.

Superheated steam has the power of taking up moisture. Thus if steam is superheated 200°F. it will absorb approximately .1

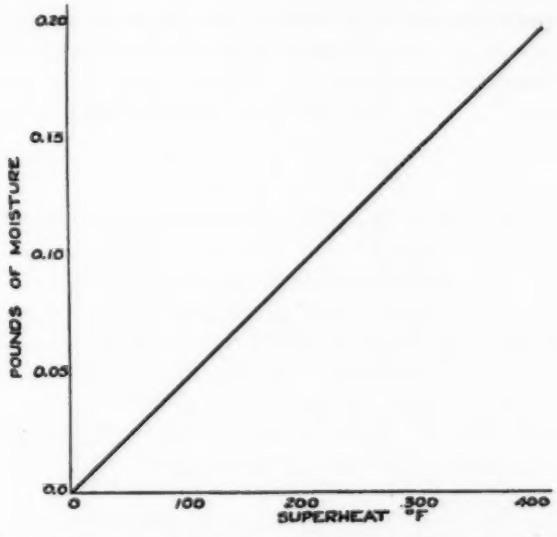

FIG. 5. CHART SHOWING THE MOISTURE ABSORBING POWER OF SUPERHEATED STEAM WITH VARIOUS DEGREES OF SUPERHEAT

pound of moisture, per pound of steam, the exact amount depending upon the pressure of the steam. (See fig. 5.)

THERMODYNAMICS INVOLVED IN STEAMING DAIRY UTENSILS

Heating utensils with steam or other media of like nature involves certain laws of heat transfer, since it is always a case of transferring heat from the medium to the utensil. The heat transferred to the utensil must be sufficient to raise the tempera-

ture of the utensil and in some cases supply a certain amount additional to care for that radiated into the air. Steaming inside a closed tank does not involve this loss, but involves radiation losses from the tank. An example of severe losses from radiation to the atmosphere is noted when a piece of equipment is heated by blowing steam against it from the outside.

It has seemed advisable to work out certain equations to serve as a guide in predicting results of steaming utensils. It should be borne in mind, however, that some of the constants used in the equations will vary for different temperatures, quality of steam, etc. The equations follow:

Equation I. Heat absorbed by a utensil during temperature rise.

$$\text{I} \qquad H = (t_2 - t_1)\ \text{sp. ht.} \times W$$

where H = heat absorbed with a temperature rise $t_2 - t_1$, in B.t.u.

t_2 = final temperature, degrees Fahrenheit.

t_1 = original temperature, degrees Fahrenheit.

sp. ht. = sp. heat of utensil = B.t.u. per degrees Fahrenheit change per pound of utensil.

W = weight of utensil, pounds.

Equation II. To find pounds of steam required to heat utensils (considering 100 per cent efficiency).

$$\text{(IIA)} \quad S = \frac{W \times (t_2 - t_1) \times \text{sp. heat}}{(h + qL) - (t_e - 32)} \text{ using wet or saturated steam}$$

or

$$\text{(IIB)} \quad S = \frac{W \times (t_2 - t_1) \times \text{sp. heat}}{h + L + C_p\,(t_{sup} - t_{sat})} - (t_e - 32) \text{ using superheated steam}$$

where S = steam required, pounds.

W = weight of utensils, pounds.

t_2 = final temperature of utensil, degrees Fahrenheit.

t_1 = original temperature of utensil, degrees Fahrenheit.

Sp. ht. = sp. heat of utensil = B.t.u. per degree Fahrenheit change per pound utensil.

h = heat of liquid of steam, B.t.u.
Q = quality of steam. Saturated = 1.00.
L = latent heat of vaporization of steam at pressure, B.t.u. per pound.
t_c = temperature at which steam condensate is removed, degrees Fahrenheit.
t_{sup} = temperature of superheated steam, degrees Fahrenheit.
t_{sat} = temperature of saturated steam at pressure given, degrees Fahrenheit.

Equation III. Heat balance at equilibrium, utensil heated over a steam jet.

$$K_1 (t_3 - t_2) = K_2 (t_2 - t_4) \qquad \text{III}$$

where K_1 = heat transfer coefficient for steam to metal of utensil, B.t.u. sp. ht./min./deg. diff. in temperature between steam and metal.
K_2 = heat transfer coefficient from external surface of metal to surrounding medium—air or vapor. Given in B.t.u./sq. ht./min./deg. diff. in temperature.
t_3 = temperature of steam, degrees Fahrenheit.
t_2 = temperature of can, degrees Fahrenheit.
t_4 = temperature of medium outside of can degrees Fahrenheit.

At equilibrium, the heat received from the steam $K_1 (t_3 - t_2)$ per unit area and time will equal the heat lost by radiation to the outside or $K_2 (t_2 - t_4)$.

Equation IV. To find time required to heat utensils submerged in steam heating medium.

$$T = \frac{(t_2 - t_1)\ (\text{sp. heat})\ W}{K_1 \left[\left(t_3 - \frac{(t_2 - t_1)}{2}\right)\right] \times S_1} \qquad \text{(IV)}$$

where T = time in minutes.
S_1 = surface of utensil exposed to steam, square feet.

Equation V. To find time required to heat utensil which is being steamed over jet.

$$(V) \quad T = \frac{(t_2 - t_1)\ \text{sp. heat} \times W}{\left[S_1 \times K_1 \left(t_3 - \frac{(t_2 - t_1)}{2}\right)\right] - \left[K_2 \left(\frac{(t_2 - t_1)}{2} - t_4\right) \times S_2\right]}$$

where T = time, minutes.
S_1 = Surface of can exposed to steam, square feet.
S_2 = Surface of can exposed to air, sq. ft.
All other symbols are described above.

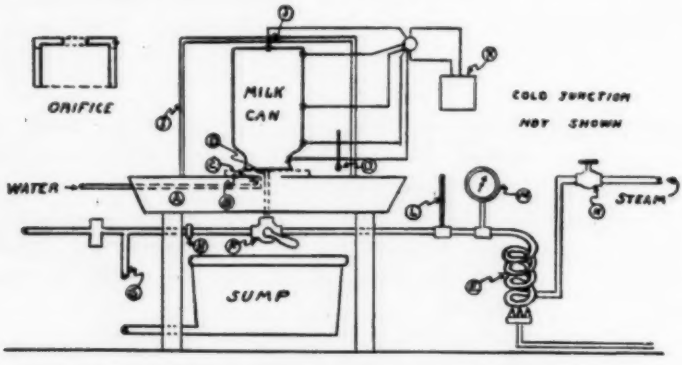

FIG. 6. DIAGRAM OF EXPERIMENTAL APPARATUS FOR STEAMING MILK CANS

TEST OF HEATING 10-GALLON MILK CANS OVER STEAM JETS

In order to study the effect of different factors on the heating of can when steamed over jets, a special apparatus shown in figures 6 and 7, was built. The essential features of this apparatus were as follows: A table, A, and an adjustable frame, B, to support the can and other parts, a water jet, C, which could be turned on and off so that the can could be easily cooled. A steam jet, D, made with a round orifice which could be easily changed for size, a superheating coil, E, heated by a gas flame for controlling the quality and temperature of the steam; a 3-way valve, F, which could be used for turning the steam quickly from the main steam jet, D, to a similar jet, H, in order to have a practically con-

tinuous and steady flow of steam through the superheater, E, so that its temperature and quality characteristics might be better controlled. The waste jet, H, carried off the waste steam. The housing, I, surrounded the can. Thermocouples, J, were soldered onto the can and connected to the millivoltmeter, K, and to a cold junction, kept at 32°F. Steam gauge, M, and thermometers, L, and, O, completed the arrangement.

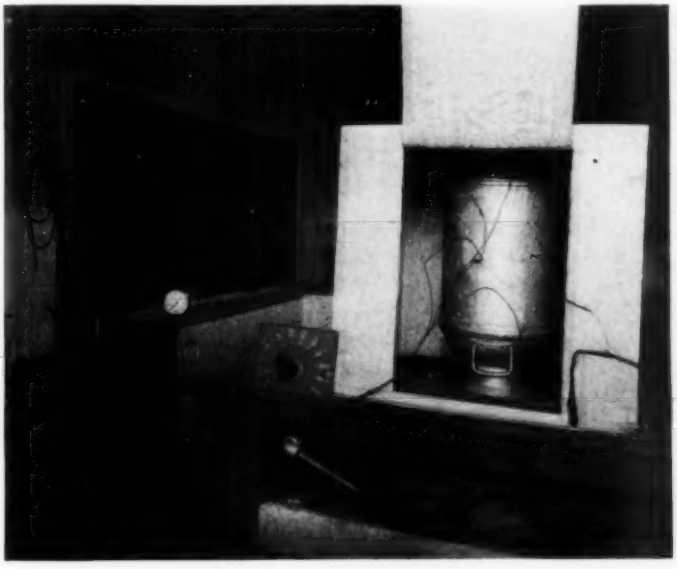

FIG. 7. PHOTOGRAPH OF APPARATUS USED FOR STEAMING MILK CANS

With this apparatus the steaming of the cans was quite closely controlled.

The general method of procedure during the tests was to place the can in position above the jet, turn on the steam to warm the can, then turn off the steam and turn on the cold water to bring the can temperature down to normal. The cycle was followed several times until the readings became constant, after which the official test was made.

Readings of the millivoltmeter were taken at five- and ten-second intervals for the period of one minute. There was some lag in the movement of the needle but it was very small, as the heat capacity of the thermocouples was small. Some practice was required in order to take the reading accurately, but this was accomplished and different tests checked closely. All data were checked at least three times. The thermocouples were moved so that different positions on the can were checked.

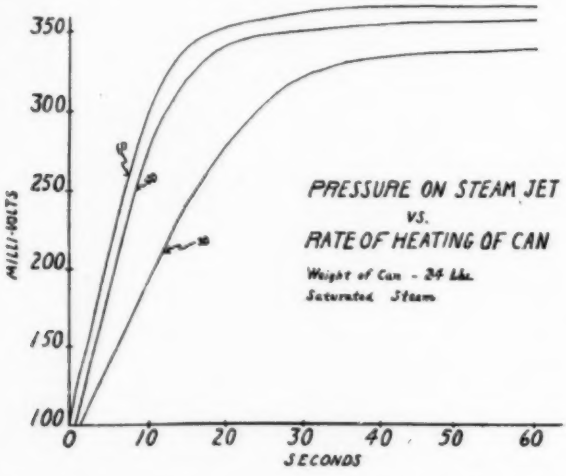

FIG. 8. CHART SHOWING THE EFFECT OF VARIOUS PRESSURES OF STEAM JET UPON THE RATE OF HEATING OF 10-GALLON MILK CAN (350 M:V = 183°F.)

EFFECT OF STEAM PRESSURE ON RATE OF HEATING

Figure 8 shows typical curves obtained when the pressure was 20, 40, and 60 pounds respectively on the 0.25 inch nozzle, and when saturated steam was used. It is significant that the rate of heating was markedly slow when only 20 pounds pressure was used, whereas there was not much difference in the rate between 40 and 60 pounds pressure. This shows that with the 20 pounds pressure, steam was not admitted fast enough to maintain the saturation temperature of the steam within the can, during the first

forty seconds, whereas with both the 40 and 60 pound pressures, the temperature was maintained practically after the first twenty seconds. It shows that the temperature in all cases finally reached a point of equilibrium at which it remained.

The practical significance of these data is that they emphasize the necessity for a large momentary volume of steam at the jet to bring the can to the proper temperature quickly, and that this volume could be decreased markedly in the interests of economy after attaining the proper temperature. A valve operated by a can in such a way that it opened quickly at first and gradually closed would be desirable. It is only a waste of steam to allow a heavy flow to continue after the can has been brought to the proper temperature.

EFFECT OF QUALITY OF STEAM UPON RATE OF HEATING

Figure 9 shows data obtained when the quality of steam was varied from wet to dry superheated, keeping all other factors constant. Steam pressure was 40 pounds and the orifice was 0.25 inch. It is interesting to note that the rate of warming of the can was very nearly the same for all during the first fifteen seconds although the very high temperature superheated steam showed somewhat more rapid heating during the first thirteen seconds. From these data it is clearly shown that wet or saturated steam heats the can more readily per degree temperature difference between it and the can than does superheated steam, however the latter will give higher final temperature if it is left on long enough. The conductivity of heat from wet steam to metal is better than from superheated steam to metal.

EFFECT OF QUALITY OF STEAM UPON AMOUNT OF MOISTURE LEFT IN CANS AFTER STEAMING

According to theory, superheated steam should have the power of absorbing moisture from the surface of the can or at least preventing an excessive amount of moisture from remaining in the can after steaming.

Figure 10 shows the results of tests, conducted in duplicate to show moisture remaining in the can after steamng for sixty

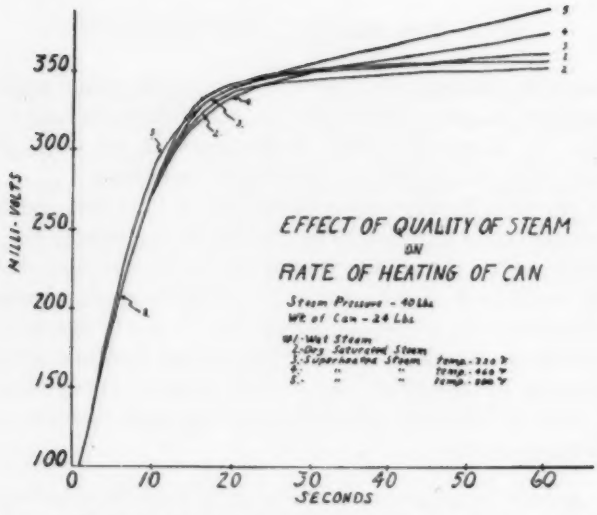

FIG. 9. CHART SHOWING HOW THE RATE OF HEATING OF A 10-GALLON MILK CAN VARIED WHEN STEAM OF DIFFERENT QUALITY WAS USED IN THE STEAM JET

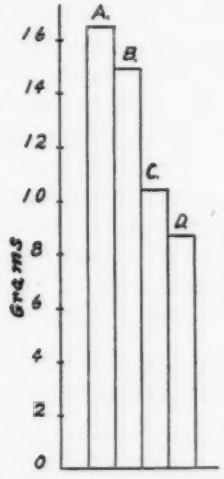

FIG. 10. CHART SHOWING GRAMS OF WATER LEFT IN 10-GALLON MILK CANS AFTER STEAMING OVER A $\frac{1}{4}$ INCH STEAM JET FOR SIXTY SECONDS

Note that the superheated steam left much less than did wet or saturated steam.

A. Wet steam at 278°F. B. Dry steam at 296°F.
C. Superheated to 420°F. D. Superheated to 532°F.

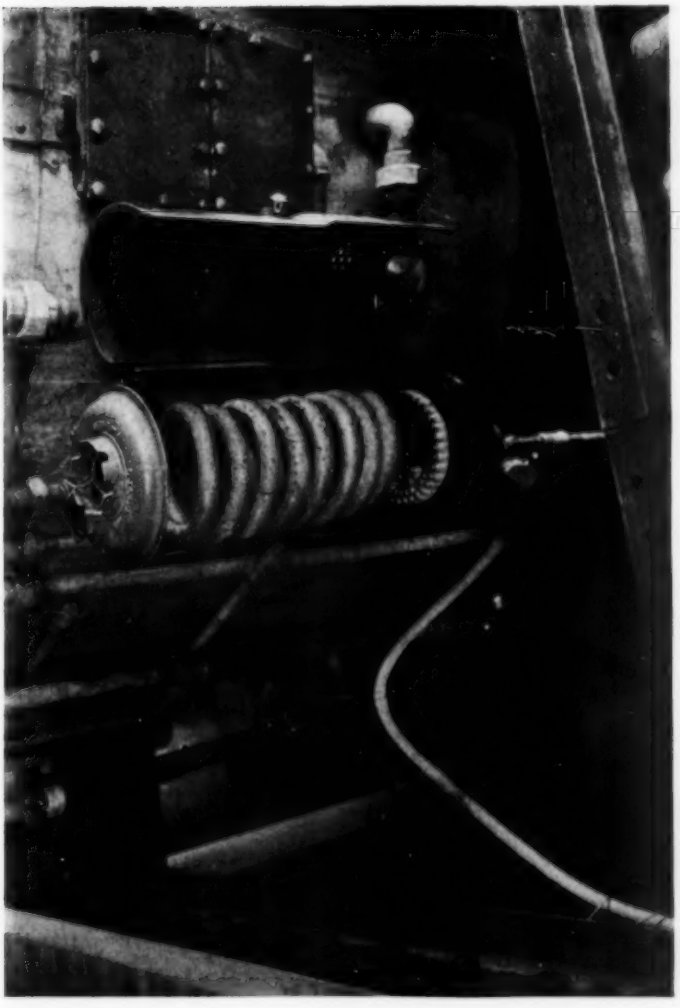

FIG. 11. PHOTOGRAPH OF A GAS HEATED SUPERHEATER ATTACHED TO THE FINAL STEAM JET OF A ROTARY CONTINUOUS CAN WASHER

seconds, using the various qualities of steam indicated. It is noted that with the wet and dry saturated steam the water was 16.30 and 14.45 grams, respectively, while with superheated steam this was cut down to 10.20 and 8.47 grams per can depending upon the temperature. The importance of this point is in the fact that if superheated steam is used in the last steam jet of a

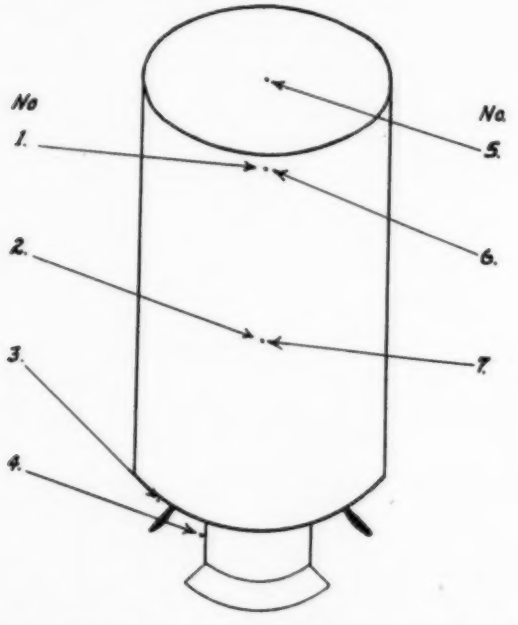

FIG. 12. CHART SHOWING POINTS AT WHICH THERMOCOUPLES WERE PLACED FOR MEASUREMENT OF VARIATION IN CAN METAL TEMPERATURE

can washer the drying process is materially aided since less moisture is left to be removed by the air drying apparatus.

This point was further tested by attaching a gas heated superheater (fig. 11) to a can washer and noting its effect. When using the superheater which furnished superheated steam for the last steam jet in a regular continuous commercial can washer, the cans usually came out with a parched dry appearance and very seldom

with any moisture present. Considerable improvement was noted in the quality of drying small St. John's cans when the superheater was used. On the washer studied the regular air dryer nozzle was so large that it practically covered the mouth of the can and prevented free circulation of air up into it. However, the small high pressure jet of superheated steam easily entered the can, and carried out most of the water. It seems that more positive drying could be brought about if the drying air was

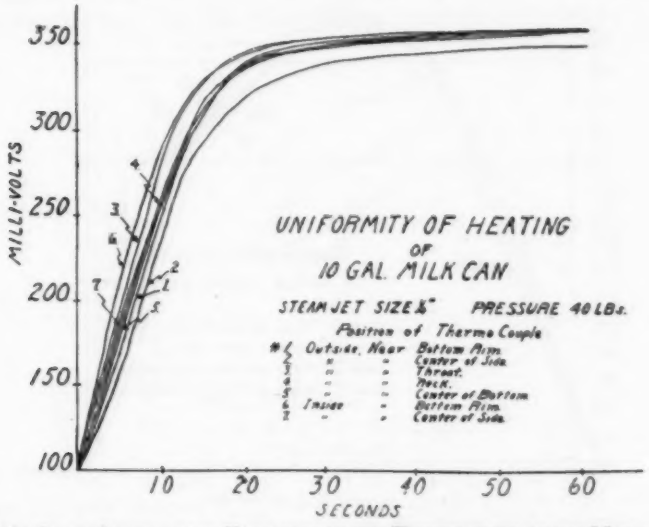

FIG. 13. CHART SHOWING THE VARIATION IN THE TEMPERATURE OF THE METAL OF A 10-GALLON MILK CAN DURING THE PROCESS OF HEATING OVER A JET OF SATURATED STEAM

forced in under relatively high pressure and forced through a smaller jet to give it sufficient velocity to travel to the top of the can and more thoroughly "scrub" the metal.

UNIFORMITY OF HEATING OF THE CAN OVER STEAM JETS

With the same apparatus, tests were conducted to measure the uniformity of heating of the can metal, and points were established as shown in figure 12 for the location of the thermocouples

as listed in figure 13. All were soldered to the outside of the can metal except nos. 6 and 7 which were carried through a small hole and soldered to the inside of the can at the same time closing the hole. Knowing the relatively high conductivity of the can metal, it would appear that the difference in rate of heating would not be appreciable with the type of jet used, since the steam was distributed quite thoroughly and there was no one place which received a strong current of steam as if a concentrating type jet

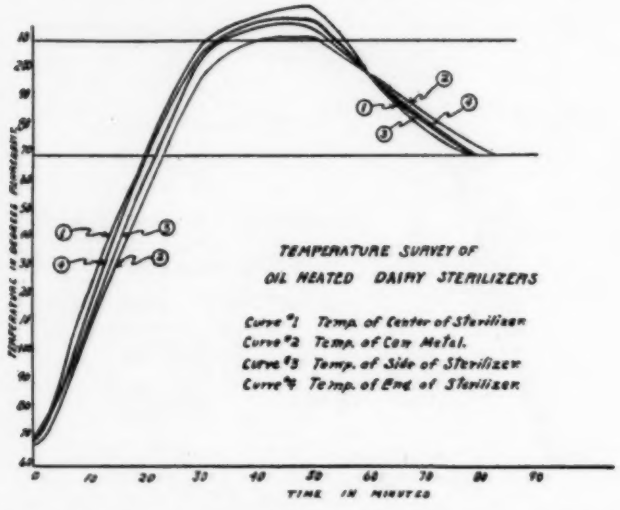
TEMPERATURE SURVEY OF
OIL HEATED DAIRY STERILIZERS
Curve #1 Temp. of Center of Sterilizer
Curve #2 Temp. of Can Metal.
Curve #3 Temp. of Side of Sterilizer
Curve #4 Temp. of End of Sterilizer
TIME IN MINUTES

FIG. 14. CHART SHOWING THE TEMPERATURES OF THE STEAM AND THE CAN METAL WHEN USING A TANK TYPE OIL HEATED STERILIZER IN WHICH STEAM WAS THE CONNECTING MEDIUM

were used. Figure 13 shows the results obtained. It is evident that the difference in the rate of heating is not great but that the most rapidly heating part is in the corner near the junction of the can bottom and side. This seems natural since it is where the condensate which is practically as hot as the steam, will tend to concentrate during the steaming process. Position 7 heated most slowly evidently due to the fact that radiation from this part of the can is quite marked, and also, there is a point where

cold air may strike, if it is drawn in with the steam. The temperature of the can metal varied 14.6°F. at the end of a fifteen-second steaming period, but only 5.7°F. after a thirty-second period. Further work is needed to measure these temperatures when other type of jets are used.

HEATING OF UTENSILS IN A CLOSED BOX

In certain types of sterilizers the utensil is heated by being placed in a chamber filled with steam. In this case the heat is applied to both inside and outside; turbulence is often poor,

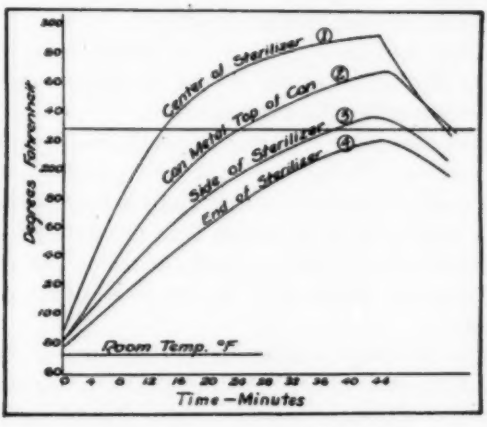

FIG. 15. CHART SHOWING THE TEMPERATURES OF THE HOT AIR AND THE CAN METAL WHEN USING AN ELECTRICALLY HEATED TANK TYPE STERILIZER IN HOT AIR WHICH WAS THE CONNECTING MEDIUM

yet quite rapid heating takes place. It is usually not necessary to heat so quickly when this method is used. Figure 14 shows time-temperature curves which indicate the rate of increase of the temperature of the can and of the sterilizing chamber. It is evident that the rate of heating of the can follows quite closely the rate of heating of the sterilizer. Figure 15 shows the results of a similar test when using hot air instead of steam as the heating medium. It will be noted that there is a considerable lag in the temperature of the can as compared with that of the heating medium in the sterilizer.

SUMMARY

1. Commercial applications of steam for sterilizing might be classified as first, steaming of cans over jets, second, steaming of cans in tank type containers, third, steaming by blowing a steam jet against the outside of the metal surface.

2. The most important properties of steam which affect its use as a sterilizing medium are as follows:

a. Temperature of saturated steam increases with pressure.

b. Temperature of steam at any given pressure may be raised by superheating.

c. Superheated steam absorbs moisture.

3. Equations are developed which state that relationship between the factors involved in the thermal exchange which takes place when milk cans are steamed.

4. The heat absorbing capacity of a milk can is limited by the area of the surface, the coefficient of heat transfer, and the temperature difference between it and the heating medium. It is unnecessary to use any more steam than just enough to maintain the temperature of the heating medium inside the can, and to give the necessary turbulence, to insure a good coefficient of heat transfer.

5. Wet and saturated steam heated the cans at higher rates per degree difference in temperature between the can and the steam than did the superheated steam. Higher final temperatures of the can were obtained when superheated steam was used.

6. With a spreading type jet made by drilling a hole in a ½ inch pipe capacity, the temperature in the can metal varied about 14.6°F. after 15 seconds steaming, and varied about 5.7°F. at the end of a half minute steaming period. The hottest part of the can was near the junction of the sides and bottom.

7. Steaming with superheated steam left much less moisture in the can than when saturated or wet steam was used.

8. The use of superheated steam in the last steam jet of a continuous can washer assists in drying the cans.

9. The time-temperature curve showing the rate of temperature rise of milk cans when heated over steam jets, rises rapidly

to a point where it flattens out sharply as the temperature is reached when there is equilibrium between heat supplied and heat radiated.

10. Milk cans when heated slowly in a steam heated tank type sterilizer, follow the sterilizer temperature closely.

11. Milk cans when heated slowly in a hot air heated tank type sterilizer, lag behind the temperature of the sterilizer to a considerable extent.

PROTEOLYSIS BY STREPTOCOCCUS LACTIS*

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INTRODUCTION

The conspicuous change brought about in milk by the growth of *Streptococcus lactis* is the coagulation resulting from the production of acid. The curd formed ordinarily shows nothing suggestive of proteolysis, even after a long period of holding, and in this respect is quite different than the curd produced through the action of the rennin-acid streptococci, such as *Streptococcus liquefaciens*. However, the appearance of a milk culture does not justify the conclusion that the organism is non-proteolytic and chemical examinations are necessary before what seem to be negative results can be accepted.

Certain investigators have reported data showing the decomposition of the protein of milk by *S. lactis* and closely related organisms, while others have failed to detect any such change. In some instances where proteolysis has been noted, the results have not been constant for a given species.

SIGNIFICANCE OF PROTEOLYSIS BY S. LACTIS

Because of the large numbers of *S. lactis* organisms present in certain dairy products, the possibility of proteolytic action due to them is of considerable significance. In the ripening of hard cheeses, for example, the decomposition of the protein is looked upon as being very important and, with the myriads of *S. lactis* organisms that develop during the early stages of the process, these microörganisms may logically be suspected of attacking the protein. The exact factors responsible for those characteristics of butter, cheeses, and fermented cream and milk, which to-

* Received for publication October 22, 1928.

gether are spoken of as flavors and aromas, are not completely understood and products which naturally result during the process of proteolysis may be involved in the development of either the desirable or undesirable flavors and aromas.

OBJECT

The primary object of the work herein reported was to determine whether or not a demonstrable proteolytic action occurs when various strains of *S. lactis* commonly isolated in Iowa are grown in milk. A number of the cultures used for developing flavor and aroma in butter were similarly studied because *S. lactis* is one of the two important types of organisms present in such cultures.

REVIEW

Both Orla-Jensen (1) and Barthel (2) mention the original statement by von Freudenreich to the effect tht he found marked digestion of casein due to organisms of the *S. lactis* group. While some investigators apparently have been unable to confirm this finding, others such as Orla-Jensen (1) Barthel (2) and Barthel and Sandberg (3) found considerable proteolysis by organisms of this type.

The *S. lactis* cultures showing protein decomposition have been isolated primarily from milk, butter culture, and cheese. In many of the investigations the trials were carried out with milk to which $CaCO_3$ had been added in amounts sufficient to neutralize all, or nearly all, of the acid that could be formed. Frequently the period of holding the cultures was as long as two or three months. Protein decomposition has been noted with *S. lactis* at various holding temperatures.

Spitzer, Parfitt and Epple (4) found that the *S. lactis* culture studied by them caused a slight increase in various groups of protein decomposition products when grown in milk or in a synthetic butter made by adding skim milk to butter fat.

PROCEDURE

The organisms used in the investigation herein reported were isolated from milk, cream, and cheddar cheese obtained from a

variety of sources. Subsequent to isolation they were kept active by transferring through a series of tubes of sterile milk. Transfers were usually made twenty-four or forty-eight hours before a trial was begun so as to have vigorous cultures from which to make inoculations. The butter cultures used were those being carried by the Dairy Section of the Iowa Agricultural Experiment Station, either for investigational purposes or as a matter of routine.

Pint milk bottles were employed as containers since these are more easily handled and stored than Erlenmeyer flasks. The thick wall is a disadvantage but by giving a little attention to the rate of heating in the autoclave the breakage is negligible. For the trials in milk, 200 cc. of skim milk were introduced into each bottle and the bottle cotton plugged, weighed and the weight recorded by marking it on a gummed label which was then fastened to the cotton plug. For the trials in which an attempt was made to neutralize some of the acid, pieces of glass and about 8 grams of finely powdered $CaCO_3$ were placed in each bottle before adding the 200 cc. of skim milk.

The bottles of milk were sterilized in an autoclave in lots of about 40. Generally about twenty minutes were consumed in attaining 15 pounds pressure and heating was continued at 15 pounds for about twenty-two minutes. After shutting off the steam, from twenty-five to thirty minutes elapsed before the door could be opened and the bottles removed. When sterilized in this manner the milk was slightly browned.

In trials that were to last only a short time, equivalent amounts of a milk culture were inoculated into the bottles receiving a given organism, while in trials lasting ten days or more, 2 or 3 drops of a culture were transferred to each bottle.

All the cultures were incubated at room temperature and those containing the added $CaCO_3$ were vigorously shaken daily for a week, and thereafter at intervals of several days.

The soluble portion of each bottle was recovered for the analytical work. In the absence of $CaCO_3$, 1 cc. of concentrated acetic acid was slowly added to the contents of each bottle while it was being gently rotated so as to avoid excessive concentration of the

added acid. The bottles were then placed in water and heated until the contents reached 60°C., after which they were removed and cooled. Water was then added to each bottle until the original weight was reached. The bottles containing carbonate were made up to 1 gram less than the original weight and then, with very little agitation, as much as possible of the milk was decanted into another bottle, care being taken to exclude glass and carbonate; 1 cc. of concentrated acetic acid was then added and the heating and subsequent cooling carried out as described. In filtering, the entire lot of milk was thrown on the filter paper at one time and the first filtrate through then returned for a second filtration because of the turbidity. There was some variation in the turbidity of the different filtrates but attempts to more completely clarify them were not successful. Often in duplicate determinations the one giving the clearer filtrate contained just as much soluble nitrogen as the more turbid one; it should not be inferred, however, that such a condition invariably prevailed.

For the nitrogen determinations, 25 cc. of the filtrate were transferred to a 500 cc. Kjeldahl flask and digested with 25 cc. concentrated sulphuric acid, about 5 grams of either sodium or potassium sulphate, a small piece of copper wire and about 2 grams of trichloracetic acid. There was usually considerable foaming but the trichloracetic acid and slow heating until the water was evaporated very materially lessened this. The ammonia was distilled into fifth normal sulphuric acid and the back titrations made with tenth normal sodium hydroxide, using alizarin as an indicator.

The amino nitrogen determinations were made according to the well known Van Slyke method, using 10.0 cc. of sample and retarding the foaming by the addition of a small, measured amount of butyl alcohol.

The lactose was determined by the official general gravimetric method.

Since preliminary trials showed that very satisfactory duplicate determinations were the rule when material from the same filtrate was used, it was considered advisable to inoculate the cultures in duplicate and then run only one determination on each

culture. The results, therefore, represent the average of two determinations made on two different filtrates.

The values for the percentage of increase in the soluble nitrogen are sometimes negative; these represent instances in which there was less soluble nitrogen in the filtrate from milk in which the organisms had developed than in the filtrate from the same lot of milk in which there had been no growth. Some work has been done in an attempt to secure an explanation of this, but the exact reasons are not clear.

RESULTS OBTAINED

1. Preliminary trials. The preliminary studies on the proteolytic action of *S. lactis* were carried out using incubation periods of ten, thirty and sixty days and data illustrating the general trend of the results are given in table 1; two trials with butter culture 122 are also included.

Without $CaCO_3$ a number of the *S. lactis* cultures gave definite proteolysis, while others yielded negative values; butter culture 122 gave definite proteolysis in both of the trials in which it was used. In milk to which $CaCO_3$ had been added, definite proteolysis occurred with a number of the *S. lactis* cultures and with the butter culture, while with some of the *S. lactis* cultures it did not. In general, when proteolysis occurred with $CaCO_3$, it also occurred without, but the proteolysis was regularly greater in the presence of the neutralizing agent. When proteolysis occurred, the percentage of the nitrogen in a soluble form ordinarily increased with an increase in the incubation period, but the protein decomposition was quite evident after an incubation of ten days.

There was some variation in the results obtained with a certain culture in different trials. *S. lactis* 1 gave definite proteolysis in trial I but not in trial IV, while *S. lactis* 2 gave proteolysis in trial II but was negative in trial IV.

2. Comparison of the soluble nitrogen increase by lactic acid and by butter cultures. Since the growth of *S. lactis* in milk is inseparably associated with the formation of lactic acid, there is the question as to whether or not the acid so produced is responsible for all or part of the change observed in the soluble nitrogen. In order to get some information on this point two trials were

TABLE 1

Proteolysis by S. lactis and butter cultures in ten, thirty and sixty days

NUMBER OF TRIAL	CULTURE NUMBER	PERCENTAGE INCREASE IN SOLUBLE N					
		No $CaCO_3$ added			$CaCO_3$ added		
		10 days	30 days	60 days	10 days	30 days	60 days
I	*S. lactis* 1	1.3	2.0	2.3	8.1	11.7	12.7
I	*S. lactis* 3	2.9	5.0	2.9	10.3	13.8	14.3
I	*S. lactis* 4				−0.1	0.6	3.9
I	*S. lactis* 7	−1.5	−0.8	−2.1	−0.9	0.4	2.9
II	*S lactis* 2	3.8	4.1	4.7	7.8	9.9	
II	*S. lactis* 6	−1.0	−1.2	−1.3	0.4	0.6	
II	*S. lactis* 8	−0.7	−0.7			4.9	
II	*S. lactis* 10	1.2	1.5	1.8		4.5	
III	*S. lactis* 5	−1.7	−1.5	−0.9	−0.7		−0.4
III	*S. lactis* 9	−2.1	−1.8	−1.0	−0,6	0.5	0.6
III	*S. lactis* 11	−2.0	−1.9	−1.4	−0.3	0.2	0.1
III	*S. lactis* 14	−1.6	−1.6	−1.1	−0.2	0.4	0.1
III	Butter culture 122	3.3	5.2	6.8	10.4	15.7	21.6
IV	*S. lactis* 1	−2.2	−1.2	−1.4	0.2	−2.0	0.4
IV	*S. lactis* 2	−1.9	−1.3	−1.1	−0.4	−2.0	0.4
IV	*S. lactis* 3	1.8	3.4	4.5	6.5	10.3	13.0
IV	*S. lactis* 4	−1.7	−1.9	−1.3	0.1	−0.4	
IV	Butter culture 122	1.5	3.3	4.6	10.0	12.8	18.2
V	*S. Lactis* 5	−0.3	−0.9		−1.0	0.5	
V	*S. lactis* 6	−1.7	−1.4		0.4	0.5	
V	*S. lactis* 7	−1.5	−1.0		−0.2	0.2	
V	*S. lactis* 8	−1.2	−0.9		−0.1	0.5	
V	*S. lactis* 9	−1.2			−0.1	1.2	

TABLE 2

Comparison of soluble nitrogen increase by lactic acid and by butter cultures

NUMBER OF TRIAL	ACIDITY FROM	PERCENTAGE OF TOTAL N IN SOLUBLE FORM			
		1 day	2 days	3 days	5 days
I	Acid A	12.0	10.9	10.9	
I	Acid B	12.2	10.8	10.8	
I	Butter culture 185	15.3	14.0	14.3	
I	Butter culture 122	15.9	14.9	14.7	
II	Acid A	10.9	10.8	11.3	11.2
II	Acid B	11.1	10.9	11.2	11.2
II	Butter culture 103	14.4	15.0	15.3	15.7
II	Butter culture 146	14.6	15.2	15.4	15.8
II	Butter culture 146–1	14.3	14.7	15.2	14.9
II	Butter culture 122	14.9	14.9	15.0	15.6

carried out in which added sterile lactic acid was compared with acid developed by butter cultures, no $CaCO_3$ being used. Two samples of lactic acid were employed, *Acid A* which had been on hand for a year or more, and *Acid B* which had just been received. After standardizing by titration, the acids were made up to suitable volumes, sterilized and added to the milk in quantities sufficient to give final acidities of 0.8 per cent. The results obtained after different incubation periods are presented in table 2, the data being expressed on the basis of the percentage of the total nitrogen that was in a soluble form. The data show that the amount of soluble nitogen found in the filtrates from each of the butter cultures was always definitely greater than that found in the filtrates from the milk to which the lactic acid had been added. Apparently the addition of lactic acid to the extent of 0.8 per cent did not appreciably proteolyze sterilized milk at room temperature; it, accordingly, appears that the lactic acid produced in milk by the microörganisms of the *S. lactis* group is not responsible for the change in the soluble nitrogen which accompanies their growth in milk.

It is of interest to note that in these trials most of the proteolytic effect of the butter cultures occurred during the first day of incubation.

3. Action of certain cultures on milk with different solid contents. Because of the variations that occurred with certain organisms on different lots of milk, an attempt was made to determine whether there were noticeable differences in the proteolytic action of cultures on milks which differed appreciably in total solids. Two lots of milk were used and were designated as *Milk A* and *Milk B*. The following data briefly show the differences between the whole milk and skim milk from the two lots; only the skim milk was used in the proteolysis trials.

	WHOLE MILK			SKIM MILK		
	Fat	Acidity	Total solids	Sugar	Protein	Ash
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Milk A	3.4	0.14	12.16	4.88	2.86	0.81
Milk B	4.5	0.16	13.86	4.61	3.52	0.84

Nine *S. lactis* cultures were used and were incubated in these milks, both with and without $CaCO_3$, for fourteen days, after which filtrates were secured and analyzed. The results obtained are presented in table 3 as the percentage increase in soluble nitrogen, the percentage increase in amino nitrogen and the percentage of sugar fermented. Three cultures (1, 14 and 39) showed no proteolysis in either lot of milk, while five cultures (23, 24, 25, 42 and 47) showed a definite action; with one culture

TABLE 3

The action of certain cultures on milk with different total solids contents

CULTURES	MILK A (LOW TOTAL SOLIDS)						MILK B (HIGH TOTAL SOLIDS)					
	No $CaCO_3$ added			$CaCO_3$ added			No $CaCO_3$ added			$CaCO_3$ added		
	Percentage increase in soluble N	Percentage increase in amino N	Percentage sugar fermented	Percentage increase in soluble N	Percentage increase in amino N	Percentage sugar fermented	Percentage increase in soluble N	Percentage increase in amino N	Percentage sugar fermented	Percentage increase in soluble N	Percentage increase in amino N	Percentage sugar fermented
S. lactis 1	−0.8	0.3	16.4	−2.1		27.9	−1.4	0.2	10.5	−1.5	0.1	20.5
S. lactis 14	−0.9	−0.1	15.9	−0.6	−0.1	33.4	−1.4	0.2	13.1	−1.1	0.1	35.1
S. lactis 23	5.1	1.7	17.6	12.0	3.8	53.6	3.4	2.0	14.6	8.7	4.5	56.8
S. lactis 24	7.1	2.2	15.2	11.3	4.3	32.2	5.5	2.2	13.5	10.5	5.7	55.1
S. lactis 25	1.2	0.6	16.2	5.0	3.0	23.4	1.6	0.8	14.6	4.5	2.9	53.8
S. lactis 26	0.6	0.1	16.8	5.3	2.1	49.4	0.4	0.3	14.6	4.5	2.8	46.0
S. lactis 39	−0.7	−0.1	12.8	−0.2	1.1	47.9	−1.0	0.0	12.9	−1.0	1.3	40.3
S. lactis 42	3.0	0.7	16.4	7.6	2.4	48.5	4.5	1.1	14.6	4.8	3.6	53.9
S. lactis 47				7.1	1.7	46.9	1.4	0.5	16.2	4.8	2.5	45.2

(26), proteolysis was definite with both lots of milk when $CaCO_3$ was added but was questionable without such an addition.

In general, the values for the percentage increase in soluble nitrogen were somewhat less in the milk with a high total solids than in the milk with a low total solids, but the differences are small and are probably explained by the greater amount of protein to be decomposed with the higher total solids.

The data show that a definite increase in the percentage of soluble nitrogen was quite regularly accompanied by a more or

less proportional increase in the percentage of amino nitrogen. This is of interest since it shows that some of the protein decomposition procedes to at least the amino acid stage.

The percentage of lactose fermented varied from 10.5 to 17.6 per cent when no $CaCO_3$ was added and from 20.5 to 56.8 when $CaCO_3$ was added. With no added $CaCO_3$, the percentage of sugar fermented was usually lower in the high solids milk than in the low solids milk but, with added $CaCO_3$, there was considerable variation; no definite difference would be expected because of the small difference in the sugar content of the two lots of milk.

4. Influence of the addition of peptone to milk. The influence of the addition of 0.3 per cent peptone to milk on the percentage

TABLE 4

The influence of added peptone on the action of S. lactis cultures in milk

CULTURES	PERCENTAGE INCREASE IN SOLUBLE N						PERCENTAGE OF LACTOSE FERMENTED					
	40 hours		60 hours		14 days		40 hours		60 hours		14 days	
	No peptone	Added peptone	No peptone	Added peptone	No peptone	Added peptone	No peptone	Added peptone	No peptone	Added peptone	No peptone	Added peptone
S. lactis 4	−0.6	−1.9	−0.5	−2.1	−1.3	−4.6	6.0	12.4	11.0	14.4	18.4	18.6
S. lactis 13	−0.5	−2.0	−1.2	−2.0	−1.9	−4.3	6.0	12.8	10.6	16.6	17.4	19.0
S. lactis 24	0.9	0.5	4.2	2.9	6.3	2.8	5.6	11.8	15.6	15.9	16.0	17.0
S. lactis 86	−0.4	−1.3	−1.8		−2.1	−3.9	8.6	11.6	8.0	11.0	15.8	16.4

increase in the soluble nitrogen and in the percentage of lactose fermented was studied using four *S. lactis* cultures and three incubation periods; the results are given in table 4. *S. lactis* 24 was the only culture which gave a definite proteolysis and, with it, the peptone appears to have retarded the protein decomposition. With the three organisms showing no proteolysis, the peptone seems, in general, to have increased the negative values. The peptone appears to have increased the lactose fermentation early in the holding period but the final percentage fermented was not definitely influenced by the addition of the peptone.

5. Proteolytic action of a series of S. lactis cultures. Since the *S. lactis* cultures studied were not consistent in their action on

TABLE 5

Comparison of the proteolytic action of various S. lactis cultures

NUMBER OF CULTURE	SOURCE OF CULTURES	GENERAL RATE OF COAGULATION	PERCENTAGE INCREASE IN SOLUBLE N	
			No $CaCO_3$ added	$CaCO_3$ added
		days		
1	Untreated milk	2	−1.2	−0.5
2A	Untreated milk	1	2.1	5.2
2B	Untreated milk	1	3.8	7.0
3	Filtered milk	2	−1.4	−0.2
4A	Untreated milk	1		9.0
4B	Untreated milk	1	6.2	11.0
5A	Commercial butter culture A	1	3.0	2.4
5B	Commercial butter culture A	1	5.7	9.7
5C	Commercial butter culture A	1	1.7	2.0
6A	Commercial butter culture B	1	5.8	10.4
6B	Commercial butter culture B	1	0.9	4.5
6C	Commercial butter culture B	1	−1.2	0.9
7A	Sour cream	1	−1.3	0.3
7B	Sour cream	1	−1.5	0.4
8A	Sour cream	1	2.0	5.4
8B	Sour cream	1	2.0	5.2
8C	Sour cream	1	1.7	7.3
9A	Sour cream	1	2.7	9.1
9B	Sour cream	1	3.5	10.8
9C	Sour cream	1	2.9	7.7
10A	Sour cream	1	2.8	11.5
10B	Sour cream	2	−1.5	0.1
11A	Sour cream	1	5.8	17.3
11B	Sour cream	1	5.7	17.8
11C	Sour cream	1	2.5	12.8
12A	Sour cream	1	2.6	13.2
12B	Sour cream	1	2.7	12.5
12C	Sour cream	1	2.3	11.1
13A	Untreated milk	1	3.4	12.2
13B	Untreated milk	1	3.5	12.7
13C	Untreated milk	1	3.9	12.4
14A	Clarified milk	1	3.1	10.8
14B	Clarified milk	1	3.3	11.0
14C	Clarified milk	1	3.3	12.3
15A	Clarifier slime	1	3.8	5.5
15B	Clarifier slime	1	3.3	5.0
15C	Clarifier slime	1	3.7	5.7
16A	Sour cream	2	0.7	−0.3
16B	Sour cream	2	0.7	

TABLE 5—*Continued*

NUMBER OF CULTURE	SOURCE OF CULTURES	GENERAL RATE OF COAGULATION	PERCENTAGE INCREASE IN SOLUBLE	
			No $CaCO_3$ added	$CaCO_3$ added
		days		
17A	Sour cream	1	4.7	12.6
17B	Sour cream	1	4.6	13.2
17C	Sour cream	1	4.6	13.1
18A	Clarified milk	1	3.4	12.0
18B	Clarified milk	2	−1.2	1.7
19A	Untreated milk	1	4.4	12.7
19B	Untreated milk	1	4.2	13.3
19C	Untreated milk	1	3.6	11.2
20	Untreated milk	4	−0.3	1.3
21	Filtered milk	4	−0.3	0.7
22A	Sour milk	2	−1.2	0.7
22B	Sour milk	1	3.4	11.5
23A	Sour cream	4	−0.6	−0.2
23B	Sour cream	2	3.4	7.0
23C	Sour cream	1	3.1	12.0
24A	Sweet cream	2	3.3	7.8
24B	Sweet cream	1	2.7	6.1
25	Untreated milk	3	−1.4	−0.4
26	Clarified milk	1	1.8	6.0
27	Clarified slime	1	2.2	9.1
28	Clarified milk	4	−1.1	−0.1
29A	Untreated milk	1	2.5	7.0
29B	Untreated milk	1	3.8	7.7
30A	Clarified milk	1	3.8	8.2
30B	Clarified milk	1	4.1	7.7
31A	Clarifier slime	2	3.3	7.6
31B	Clarifier slime	3	−0.6	−0.2
32A	Untreated milk	1	2.0	6.0
32B	Untreated milk	1	2.3	6.6
33	Untreated milk	3	−0.1	0.6
34A	Untreated milk		−0.6	10.5
34B	Untreated milk	1	3.0	8.4
35A	Sour cream	1	2.9	5.7
35B	Sour cream	1	2.8	7.8
36A	Cheese	1	3.5	6.7
36B	Cheese	1	2.8	7.4
36C	Cheese	1	2.2	6.5
36D	Cheese	2	2.8	8.7
37A	Sour cream	1	0.8	3.3
37B	Sour cream	1	1.5	5.0

TABLE 5—*Concluded*

NUMBER OF CULTURE	SOURCE OF CULTURES	GENERAL RATE OF COAGULATION	PERCENTAGE INCREASE IN SOLUBLE N	
			No $CaCO_3$ added	$CaCO_3$ added
		days		
38A	Sour cream	7	−0.5	−0.6
38B	Sour cream	7	−1.2	
38C	Sour cream	2	3.2	7.7
39A	Cheese	7	−1.0	−1.0
39B	Cheese	Not curdled in 2 weeks	−0.8	−0.3
39C	Cheese	1	2.2	
40	Cheese	7	−1.0	−0.6
41	Untreated milk	7	−1.4	−0.6
42	Butter culture	1	2.2	3.9

the protein of milk, it seemed advisable to study a considerable number of additional cultures. The cultures used were isolated from untreated, filtered and clarified milk, clarifier slime, sweet and sour cream, butter culture, and cheese. The proteolytic action was tried out, both with and without $CaCO_3$, using fourteen days incubation at room temperature. The results obtained, together with the general rate of coagulation, are given in table 5. Each source is designated by a number and the different letters indicate different isolations from the source.

The data show that some of the cultures caused a very definite proteolysis, while others did not. A comparison of the action of each organism with its rate of coagulation shows that, in general, the cultures which caused a definite proteolysis were the ones which were rapid coagulators, while those causing little or no increase in soluble nitrogen brought about a slow coagulation. In accordance with the results already given, the proteolysis was more extensive when $CaCO_3$ was added than when it was not.

6. Proteolytic action of a series of butter cultures and a series of associated organisms. The proteolytic action of a number of butter cultures from various sources and of a number of the organisms associated with *S. lactis* in butter cultures (*Streptococcus citrovorus* and *Streptococcus paracitrovorus*) was determined, with

and without $CaCO_3$, and the results are given in table 6. Incubation was for fourteen days at room temperature. The data show that the butter cultures regularly caused proteolysis, while the cultures of associated organisms did not. With the butter cultures, proteolysis was again regularly increased by the addition of $CaCO_3$ to the milk.

TABLE 6

Proteolytic action of a series of butter cultures and a series of associated organisms

	PERCENTAGE INCREASE IN SOLUBLE N	
	No $CaCO_3$ added	$CaCO_3$ added
Butter culture A	3.0	
Butter culture B	3.5	
Butter culture 103	3.8	9.7
Butter culture 122	3.9	10.8
Butter culture 144	4.2	
Butter culture 146	4.0	9.0
Butter culture 146-1	1.5	
Butter culture 182	2.9	8.3
Butter culture 183	3.5	
Butter culture 185	3.8	
S. citrovorus 5	−0.1	−0.4
S. citrovorus 6	1.1	
S. paracitrovorus 17A	−1.0	−0.5
S. paracitrovorus 2B	0.6	
S. paracitrovorus 2C	−1.4	

DISCUSSION OF RESULTS

The data showing proteolysis with certain *S. lactis* cultures confirm the findings of various investigations along this line. The proteolysis noted with the butter cultures is undoubtedly to be attributed to the *S. lactis* organisms contained since, in the trials carried out, the associated organisms failed to fragment the protein. The increased proteolysis when $CaCO_3$ was added and occasionally distributed by agitation during the fermentation was probably due to an increased growth of the organisms that resulted from keeping down the acidity. Under practical dairy conditions there may be factors which tend to favor proteolysis by *S. lactis* through their influence on the acidity; for example,

in old cream held at comparatively high temperatures, the action of molds may reduce the acidity near the surface.

The failure to secure an increase in the soluble nitrogen when sterile lactic acid was added to milk in quantities comparable to those developed by *S. lactis* suggests that the protein decomposition with this organism is due to an enzyme. This enzyme does not show the rapid and extended activity of some of the proteolytic enzymes produced by bacteria, although it does cause a considerable increase in the soluble nitrogen under certain conditions and might easily influence various characters of dairy products, including the flavor and aroma. The increase in the amino nitrogen, as measured by the Van Slyke method, indicates that the protein decomposition goes at least to the amino acid stage. Unpublished results recently secured at the Iowa Agricultural Experiment Station indicate that with certain *S. lactis* cultures the development of ammonia sometimes occurs.

The relationship between protein decomposition and the rate of coagulation suggested by the data presented is of interest because of the variations in the protein decomposition noted by different investigators. The question naturally arises as to whether certain organisms grow slowly because they cannot successfully attack the protein or whether they do not attack the protein because they grow so slowly. Preliminary data which have not been included show that the addition of peptone or certain amino acids to milk into which some of the slow coagulators were inoculated increased the rate of coagulation. This suggests that the organisms may be limited in their growth in normal milk through their inability to satisfy their nitrogen requirements.

The proteolytic action of *S. lactis* may be a factor in various changes that occur in dairy products, such as the protein decomposition in various types of cheese and in butter. The development of flavors and aromas, both desirable and undesirable, in dairy products may be influenced by this proteolysis. The variations in the proteolytic activity of the *S. lactis* organisms present some interesting possibilities in connection with the study of dairy products, especially along the line of the development of butter cultures for special purposes.

CONCLUSIONS

1. Certain cultures of *S. lactis* showed a definite proteolytic activity in milk, while others did not.

2. The butter cultures studied regularly showed proteolysis in milk.

3. When $CaCO_3$ was added to the milk and occasionally distributed by agitation, proteolysis was more pronounced with *S. lactis* cultures and butter cultures than when $CaCO_3$ was not used.

4. Sterile lactic acid added to milk in quantities approximating those developed by *S. lactis* cultures did not increase the amount of soluble nitrogen on holding at room temperature.

5. When there was an increase in soluble nitrogen through the growth of *S. lactis* in milk, there was usually an increase in the amino nitrogen as determined by the Van Slyke method.

6. The addition of peptone appeared to retard protein decomposition rather than accelerate it.

7. In general, protein decomposition with *S. lactis* occurred with cultures coagulating milk rapidly, while no decomposition took place with cultures coagulating slowly.

8. *S. citrovorus* and *S. paracitrovorus* did not cause proteolysis when grown in milk.

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THE EFFECTS OF CERTAIN SALTS ON THE PHYSICAL PROPERTIES OF ICE CREAM MIXES*

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INTRODUCTION

It is recognized that the properties of ice cream mixes may not be uniform from day to day although the mixes appear to have been prepared in the same manner. Different amounts of salts naturally occurring in milk and cream may account for some of the variations in the viscosity of and ease of whipping an ice cream mix. With this idea in mind, the effect of adding sodium or calcium salts, on the viscosity, ease of whipping, and fat globule clumping was determined. Sodium and calcium salts naturally occurring in milk and those used as neutralizers were compared. The calcium in ice cream mixes was precipitated by potassium oxalate and oxalic acid to secure further data on the importance of calcium salts.

EXPERIMENTAL METHODS

The correct proportions of the ingredients in the mix were calculated by the method of Price (1). Cream, skimmilk, powdered skimmilk, water to dissolve gelatin, 0.5 per cent of a medium grade gelatin, and 14 per cent of sugar were the ingredients used in all but four of the experiments. In two experiments butter, skimmilk powder, water, gelatin, and sugar were used and in two other trials skimmilk was used in place of the water. The percentages of fat and serum solids in the finished ice cream were 12 and 10, respectively. The ice cream mixes were pasteurized at 62° to 64°C. (144° to 148°F.) for thirty minutes or at 65°C. (150°F.) for twenty minutes.

From 100 to 200 pounds of mix were prepared for each series of trials. For tests on mixes of normal acidity the former amount

* Received for publication October 15, 1928.

was divided into 15 pound lots to which the various salts were added. The salts were always added as a concentrated solution in water to the cold mix before pasteurization and homogenization or to the mix after homogenization as soon as it was cooled. When 200 pounds of mix were prepared half of this quantity was set at 21°C. (70°F.), either with or without the addition of a commercial starter, to develop lactic acid prior to pasteurization. If the starter was added to one portion of the mix an equal amount of skimmilk was added to the other portion. The two portions were divided into 15 pound lots and the same salts were added as before.

The mixes were poured directly into a funnel attached to a Manton-Gaulin homogenizer of 60 gallons per hour capacity. They were processed at the pasteurization temperature and at 2000 pounds pressure per square inch. The mixes were cooled in shot gun cans placed in ice water and were aged at 3° to 5°C. (37° to 41°F.) for fifteen to twenty hours prior to freezing. The mixes were frozen for uniform periods of time in one gallon freezers under identical conditions. The brine temperature was controlled within 0.2°C. and the temperature of the finished ice cream varied half this amount. Some of the results were verified under commercial conditions.

The viscosity of the mix was determined with the MacMichael Viscometer, operated under conditions recommended for the apparatus, using the number 22 and 26 wires which had been standardized by oils of known viscosity furnished by the United States Bureau of Standards. The results obtained were expressed as viscosity in centipoises even though plasticity may have influenced the reading. A more feasible means of determining or stating the fluid characteristics of the mixes was not available. The temperature of the mix, when viscosity determinations were made, varied from 3° to 5°C. but was uniform for each series.

The acidity of the mixes was determined by titration with N/10 sodium hydroxide using phenolphthalein as an indicator.

The fat globules were measured at a magnification of approximately 2000 diameters using an ocular micrometer disc standardized with the microscope so adjusted that each of the smallest

marks represented 0.625 micron. One-half cubic centimeter of the mix to be examined was diluted with 100 cc. of distilled water and mounted as a hanging drop preparation.

The ice cream samples were scored for body, texture, and flavor, without knowing their identity at the time of scoring.

EXPERIMENTAL

The effect of salts on viscosity, fat clumping, and ease of whipping

Sommer (2) reported that the ease of whipping ice cream mixes was greatly increased by adding 0.40 or 0.56 per cent of sodium citrate or 1.26 per cent di-sodium phosphate to the mix before aging. Calcium lactate added to the extent of 0.1 and 0.2 per cent had a noticeable effect and 0.5 per cent had a marked effect in reducing the ease of whipping of ice cream mixes. These results have been confirmed in this investigation. In a later article he (3) reported that these results could not always be duplicated.

Sodium and calcium salts naturally occurring in milk and potassium oxalate to precipitate the calcium present in milk were used in the first experiments. Five-tenths of 1 per cent of sodium citrate, potassium oxalate and di-sodium phosphate and 0.2 per cent of calcium lactate were added separately to four portions of an ice cream mix before homogenization, and also to four portions of the same ice cream mix after homogenization.

Table 1 shows the effect these salts had on the viscosity of the ice cream mixes and the percentage of overrun obtained. The sodium salts and the potassium oxalate, added before pasteurization, caused the mixes to be less viscous and whip more readily than the control, whereas the addition of calcium lactate caused the mixes to be very viscous and hard to whip. The addition of 0.5 per cent of calcium lactate caused the mix to curdle excessively as it came through the homogenizer. Even 0.2 per cent caused a small amount of curdling.

The sodium salts added after homogenization did not affect the viscosity of the mixes to any great extent but did improve the ease of whipping. The calcium salts gave practically no effects when added after homogenization.

TABLE 1

Effect on the viscosity and ease of whipping of adding salts to ice cream mixes

EXPERIMENT NUMBER	VISCOSITY IN CENTIPOISES					OVERRUN PERCENTAGE				
	Control	Potassium oxalate	Sodium citrate	Di-sodium phosphate	Calcium lactate	Control	Potassium oxalate	Sodium citrate	Di-sodium phosphate	Calcium lactate
	Salts added before homogenization									
1	3,050	40	43	164	2,020	69	112	110	106	29
2	190	49	54	112	4,680	87	111	100	107	50
3	220	43	41	115	5,010	78	97	101	91	34
4	2,980		1,140		3,850	51		102		30
5	2,130	51	41			74	98	95		46
	Salts added after homogenization									
2	190	179	271	231	242	87	113	103	105	95
3	220	75	350	520	360	78	102	104	85	64
4	2,980		3,400		2,450	51		97		38
5	2,130	370	450			74	97	112		

TABLE 2

Effect on the size of fat globules and fat globule clumps of adding salts to ice cream mixes

SALTS ADDED	NUMBER OF INDIVIDUAL GLOBULES MEASURED	AVERAGE SIZE OF GLOBULES	NUMBER OF CLUMPS MEASURED	AVERAGE SIZE OF CLUMPS
	Salts added before homogenization			
		microns		*microns*
Control	333	1.34	367	5.64 × 3.29
Potassium oxalate	200	1.55		No clumps
Calcium lactate	126	2.03	64	13.08 × 8.33
Sodium citrate	400	1.11	238	2.58 × 1.37
Di-sodium phosphate	100	1.54	100	4.67 × 2.37
	Salts added after homogenization			
Potassium oxalate	80	1.47	54	2.5 × 1.37
Calcium lactate	160	1.46	221	5.76 × 3.27
Sodium citrate	200	1.53	220	5.63 × 3.02

Table 2 gives the average size of individual fat globules and fat globule clumps taken from measurements made in several of the experiments. These are representative of what was found on other slides examined. The mixes to which sodium salts had been added before pasteurization and homogenization contained smaller fat globule clumps. When calcium lactate was added to mixes before pasteurization and homogenization the viscosity and size of fat clusters were increased and whipping was made more difficult. The potassium oxalate mixes were the only ones which have been found to contain no fat globule clumps. One might venture the assumption that the presence of calcium salts was an essential in securing clusters of fat globules by homogenization for no clumps were found in the mixes free from soluble calcium.

The salts added after homogenization did not affect the fat globule clumping except that a slight decrease in the size of clumps was noticed when potassium oxalate was added.

The results of this investigation should not be interpreted to signify the desirability of using any of these salts commercially but rather to show reasons for variations of the properties of ice cream mixes. The ice cream to which sodium citrate, di-sodium phosphate, calcium lactate or potassium oxalate was added was not as fresh in flavor as the control. The potassium oxalate would be very objectionable in commercial ice cream as it is a poison.

The effect of neutralizers on viscosity, fat clumping and ease of whipping

Bendizen (4) reports a trend toward a reduction in overrun with an increase in naturally developed acid. He found no direct relation between the viscosity of mixes and overrun and between viscosity and acidity in untreated mixes. Sodium hydroxide was found to be preferable to calcium hydroxide since sodium hydroxide only reduced the overrun 8.8 per cent as compared to 16.9 per cent reduction by the use of calcium hydroxide. His experiments show that neutralizing the whole mix just before freezing always increases viscosity. Neutralization of the con-

TABLE 3

Effect on the viscosity and ease of whipping of adding salts and acids to ice cream mixes of normal acidity and to mixes which have been allowed to develop lactic acid

Experiment Number	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	1	2	3	4
Salt added	Titratable acidity					Viscosity centipoises					Overrun percentage					Viscosity centipoises				Overrun percentage			
	Mixes of normal acidity																						
	Added before homogenization															Added after homogenization							
Control	0.20	0.20	0.21	0.22	0.235	76.0	270.0	152.0	578.0	2,130.0	94.7	78.1	84.8	87.0	74.0	76.0	270.0		578.0	94.7	78.1	84.8	87.0
Sodium bicarbonate	0.17	0.17		0.21	0.19	63.5	64.0		76.0	161.0	97.0	97.9		102.0	102.0	163.0	296.0		580.0	78.6	75.1		80.2
Calcium hydroxide	0.16	0.15		0.16	0.20	189.0	289.0		225.0	1,360.0	79.3	75.3		90.3	74.0	177.0	400.0		705.0	73.5	66.2		69.6
Sodium hydroxide	0.11	0.12				45.0	49.0				90.0	94.7				304.0	680.0			83.5	81.0		
Citric acid	0.31		0.28			7,440.0		6,800.0			46.6		56.2					126.0				98.0	
Oxalic acid	0.295		0.30			1,140.0		302.0			80.0		95.8			68.0		125.0		108.0		96.0	
			0.26					113.0					88.4										
Lactic acid			0.28					6,500.0					38.0					122.0				95.5	
	Mixes in which acid has been developed																						
Control	0.37	0.27		0.275	0.285	6,300.0	8,100.0		7,350.0	7,460.0	33.4	31.3		43.0	47.7	6,300.0	8,100.0		7,350.0	33.4	31.3		43.3
Sodium bicarbonate	0.23	0.26		0.23	0.22	150.0	410.0		380.0	127.0	75.8	80.5		90.6	94.6	5,760.0	6,270.0		5,400.0	38.0	39.5		43.3
Calcium hydroxide		0.22		0.23	0.22	1,720.0	7,030.0		3,120.0	560.0	50.0	35.9		52.9	67.5	5,800.0	5,930.0		6,920.0	34.0	25.7		35.9
Sodium hydroxide	0.17	0.21				80.0	290.0				90.4	93.0					6,060.0				33.7		

densed skimmilk effected overrun the least and neutralization of the cream the most.

Dahle (5) and Fisher (6) report an increase in viscosity of mixes which are high in acid at the time of homogenization and these mixes could not be whipped to the same overrun as the control. Dahle (5) showed that neutralization improved the ease of whipping but that whipping was not as easy as in the original.

From the preceding results it seemed probable that when sodium salts were used as neutralizers they should produce mixes more easily whipped than when calcium salts were used. Experiments were conducted with the following common neutralizers: sodium bicarbonate, sodium hydroxide and calcium hydroxide. These were dissolved in water and used in quantities calculated as being sufficient to neutralize 0.1 per cent lactic acid. These quantities, expressed on the basis of dry neutralizer, were 0.1 per cent baking soda, 0.04 per cent quick lime, and 0.044 per cent sodium hydroxide. In some trials citric, oxalic, and lactic acids were added to the ice cream mixes, as well as allowing the acidity of certain mixes to increase by natural souring.

In the experiments reported in table 3 neutralizers and acids were added to mixes of normal acidity and to those in which acidity was allowed to develop.

The addition of sodium bicarbonate or sodium hydroxide before homogenization to mixes of normal acidity caused them to whip easier. This was especially noticeable when the control was a little difficult to whip. Their addition after homogenization did not have the same effect.

The addition of lactic or citric acid to ice cream mixes in amounts which increased the titratable acidity to 0.28 to 0.30 per cent caused some curdling when homogenized. These mixes were very viscous and difficult to whip. The addition of the same amount of citric or lactic acid after homogenization did not increase the viscosity of the mix and it whipped very readily. Oxalic acid added in amounts to give a similar titratable acidity either before or after homogenization did not cause the mixes to curdle and did not prevent them from whipping readily.

The mixes in which lactic acid was allowed to develop in

amounts which increased the initial titratable acidity to 0.28 to 0.30 per cent curdled some at the time of homogenization, became very viscous, and were difficult to whip. The addition of sodium bicarbonate or sodium hydroxide to these mixes before pasteurization prevented them from becoming unusually viscous and they whipped very readily. When calcium hydroxide was added as a neutralizer the viscosity of the mixes was not reduced as much and they did not whip nearly as readily as those to which sodium bicarbonate or sodium hydroxide had been added. The neutralizers added after homogenization did not reduce the viscosity or improve the ease of whipping.

The low acid mixes to which sodium bicarbonate and calcium hydroxide had been added were very similar in flavor and quality to the control. The flavor of the ice cream containing the sodium hydroxide was slightly pungent.

The ice cream made from mixes which had acid added to them was hard and crumbly but did not taste sour. The ice cream from neutralized mixes in which the acidity was allowed to develop was hard and crumbly and tasted slightly sour. Of the three neutralizers used the best flavored ice cream resulted when sodium bicarbonate was used. The calcium hydroxide did not give as fresh a flavor and the sodium hydroxide gave a neutralizer flavor. The higher the acidity of a mix when it is neutralized the greater the danger of securing neutralizer flavors.

Everyone realizes that the successful manufacture of ice cream of high quality can be effected only through the use of ingredients of high quality. This work shows that when such materials are used and some difficulty is encountered in obtaining the desired overrun the addition of enough sodium bicarbonate calculated to neutralize 0.1 per cent acidity would relieve this difficulty. Likewise when a mix has developed some acidity sodium bicarbonate added before pasteurization will reduce the viscosity, cause the mix to whip easier and improve the flavor of the resulting ice cream.

When mixes were prepared using either unsalted butter, skimmilk powder, and water, or unsalted butter, skimmilk powder, skimmilk, and enough water to mix with or dissolve the gelatin

and salts different results were obtained. These results are presented in table 4.

The portions of the mixes in which acidity was increased with a pure culture lactic starter were not as viscous after homogenization as the mixes of normal acidity and they whipped to a little higher overrun. These mixes were all unusually viscous yet they whipped very readily. This is contrary to practically all the other results and should be studied further before a positive statement can be made on this particular point. The control

TABLE 4

Effect on the viscosity and ease of whipping of adding salts to ice cream mixes prepared with butter, skimmilk powder and water or skimmilk

Experiment Number.....	1	2	3	4	1	2	3	4	1	2	3	4
Salts added	Titratable acidity				Viscosity centipoises				Overrun percentages			
	Mixes of normal acidity											
Control	0.22	0.20	0.22	0.24	6,000	4,400	1,790	1,335	90	87	99	105
Sodium bicarbonate	0.16	0.19	0.18	0.18	1,885	2,980	970	612	97	93	107	101
Calcium hydroxide	0.14	0.15	0.16		2,770	4,790	1,810		90	79	98	
Sodium citrate	0.18	0.20	0.21		490	852	332	332	107	102	104	97
Calcium lactate	0.235	0.23	0.25	0.24	8,880	8,900	4,870	3,960	34	47	54	82
	Mixes in which acid has been developed											
Control	0.30	0.25	0.28	0.56	2,590	3,110	2,330	9,300	104	115	109	101
Sodium bicarbonate	0.26	0.25	0.23	0.25	1,745	2,620	1,680	8,700	106	107	116	94
Calcium hydroxide	0.23	0.23	0.22	0.33	1,750	2,450	2,270	11,430	100	105	100	44
Sodium citrate	0.27	0.27	0.28	0.47	435	465	380	1,450	101	98	108	94
Calcium lactate	0.31	0.28	0.28		6,130	3,500	6,680		80	84	61	

whipped so well that the addition of sodium bicarbonate, or sodium citrate did not improve the ease of whipping. The addition of calcium lactate, however, made them more difficult to whip. Mention should be made of the fact that the control mixes with high acid curdled during processing. The control mix with a titratable acidity of 0.56 per cent was warmed to 100°F. and homogenized. This mix was curdled and could not be heated to pasteurization temperature before homogenization. It was possible to warm the neutralized portions of this mix to

62.5°C. (145°F.) before homogenization without excessive curdling. These mixes all bothered in passing through the homogenizer and a constant pressure could not be maintained. A number of uncontrolled factors might cause variations in this particular experiment.

The control prepared with fresh unsalted butter, skimmilk powder, and water was not fresh in flavor. The sodium bicarbonate and calcium hydroxide gave them a little fresher flavor. The sodium citrate produced a salty flavor in the ice cream. The ice cream containing calcium lactate was always poor due to the low overrun obtained. Those mixes which were high in acidity all had a very peculiar sour flavor. The sodium bicarbonate and calcium hydroxide did not counteract this flavor completely but brought about some improvement.

SUMMARY AND CONCLUSIONS

The addition of sodium citrate, potassium oxalate, (poisonous) and di-sodium phosphate to ice cream before pasteurization and homogenization reduced their viscosity and caused them to whip easier. The size of the fat globule clumps in these mixes were smaller. There appeared to be a relationship between the size of fat globule clumps and viscosity. Calcium lactate increased the viscosity and size of fat clusters and made it more difficult to whip. The addition of these salts after homogenization did not have a marked effect on viscosity or size of fat globule clumps but in some cases did affect the ease of whipping the mixes.

A natural increase of lactic acid to approximately 0.30 per cent or the addition of lactic or citric acid to ice cream mixes before pasteurization and homogenization caused them to curdle slightly at the time of homogenization and become very viscous and difficult to whip. The ice creams made from these mixes were hard and crumbly. Oxalic acid added either before or after homogenization or citric or lactic acid added after homogenization did not have this effect. The exceptional action of oxalic acid was attributed to the observed precipitation of calcium.

The addition of sodium bicarbonate and sodium hydroxide to mixes of normal acidity caused them to be less viscous and to

whip easier than the control. Calcium hydroxide did not have this effect. Sodium bicarbonate and sodium hydroxide in comparison with calcium hydroxide when used to neutralize ice cream mixes with a titratable acidity of 0.28 to 0.30 per cent produced less viscous and easier whipping mixes. Sodium bicarbonate produced a better flavored ice cream than that produced by the other neutralizers.

The mixes prepared with unsalted butter, skimmilk powder, skimmilk or water were unusually viscous but they all whipped very easily. These mixes, high in acid when pasteurized and homogenized, whipped even better than those of normal acidity. They whipped so well the sodium salts had no effect in this respect but the calcium lactate reduced the ease of whipping.

As a result of these studies it appears probable that the relative amounts of sodium and calcium salts in the ice cream mix made from normal dairy products varies sufficiently to affect the whipping properties of the mix. The mixes prepared from dairy products secured from the same source of supply are not entirely uniform, but when difficult whipping was encountered it was uniformly corrected and a less viscous mix resulted by the addition of 0.1 per cent baking soda prior to pasteurization.

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METALS IN DAIRY EQUIPMENT

METALLIC CORROSION IN MILK PRODUCTS AND ITS EFFECT ON FLAVOR*

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At the present stage of dairy development, contact of milk with metal surfaces in dairy equipment appears inevitable. Milk is exposed to metal surfaces from the time of its production, through the various stages of handling and manufacture, to the packing of the finished product for market. Experience in the use of diverse metals in milk work has demonstrated marked differences in suitability of metals for dairy equipment. These experiences have convincingly shown that suitability of metals is not confined alone to those properties that deal with structural features, heat conductivity and durability, but that it demands serious consideration also of the relation of metals to the flavor and keeping quality of the milk product.

The status of metals in dairy equipment, their properties, resistance to corrosion, and their effect on flavor and keeping quality of dairy products, was brought before the World's Dairy Congress in 1923 by Seligman (1) and Hunziker (2). The past five years have seen new metals and alloys introduced, and additional information has become available on the prominent rôle which corrosion may assume in the life of the equipment and in the maintenance of desirable flavor, keeping quality, and wholesomeness of the dairy product.

It is not the purpose of this discussion to review in detail the theories of metallic action and the plant experiences brought out in the above papers. The present paper deals with the results of

* Received for publication October 19, 1928.

specific experiments on corrosion of metals, plated metals, and metallic alloys in contact with diverse milk products and the effect of such contact and corrosion on the flavor of the milk product. In interpreting these new results, however, it is important to take cognizance of the more fundamental facts and theories advanced in the earlier papers above referred to which may be briefly summarized as follows:

In order for any metal to suffer corrosion or to affect the dairy product it must be capable of entering into solution. Such solution may result from the attack of acids, mineral salts, and other constituents of milk as well as from contact with washing powders, chemical sterilizers, brine, etc.; or it may be caused by electrolysis set up in the product itself, or by stray electric currents from imperfectly insulated electrical equipment or conduits within the milk plant or in close proximity. Air has been found to intensify corrosion, making the effect at the air-liquid line and similar points of air contact particularly marked. Injury to the flavor and keeping quality of the dairy product may be caused by the presence, even in very minute amounts, of the metallic salts themselves which have a metallic, bitter, puckery flavor; or by oxidative or catalytic action of these salts, or by bacteria-selective influence of certain metallic salts. Furthermore, it was shown that the salts and oxides of certain metals have distinct toxic properties rendering the product unsafe for consumption.

EXPERIMENTAL

This experiment embraces a study of the corrosive effect of milk and milk products on the various metals used in dairy equipment and the effect of such metals on the milk product itself. This involves extensive laboratory tests, and observations in commercial plant operation.

Materials used. The laboratory tests included 19 different metals, plated metals, and metallic alloys. These metals were used in the form of strips 4 inches long and $1\frac{3}{8}$ inches wide, and were as follows:

Single metals	*Plated metals*	*Metallic alloys*
Aluminum*	Galvanized iron	Allegheny Metal†
Copper	Tinned copper	Ascoloy†
Iron	Edges bare§	Enduro Type "A"§§
Nickel	Edges tinned**	Mang. aluminum alloy*
Tin	Copper Retin‡	Monel Metal
Zinc	Tinned iron	Nickel silver
	Edges bare††	
	Edges tinned‡‡	
	Manganese aluminum alloy (Al. plated)*	

* Furnished by the Aluminum Company of America. The aluminum is the pure metal in a soft condition. The manganese aluminum alloy consists of 1.25 per cent manganese and the balance aluminum.

† Furnished by the Allegheny Steel Company. Ascoloy is an ordinary chromium steel alloy, containing approximately 12 to 16 per cent Cr, 0.5 per cent Si, 0.5 per cent Mn., 0.025 per cent P, and 0.025 per cent S. Allegheny Metal is a special chromium steel alloy, containing 17 to 20 per cent Cr, 7 to 10 per cent Ni, and less than 0.5 per cent Mn, 0.5 per cent Si, 0.025 per cent P, and 0.025 per cent S.

‡ Furnished by the Sorensen Speciality Company. This is copper coated with a tin preparation which can be applied to renew the tinned surface without use of flux. The tin coating was very heavy.

The remaining metals were furnished by J. G. Cherry Company.

§ Represents copper strips the cut edges of which were not tinned.

** Represents copper strips the cut edges of which were tinned.

†† Represents iron strips the cut edges of which were not tinned.

‡‡ Represents iron strips the cut edges of which were tinned.

§§ Enduro Type "A" is an ordinary or straight chromium steel containing 16.5 per cent to 18.5 per cent Cr, 0.5 per cent to 1.25 per cent Si, and less than 0.1 per cent C, 0.5 per cent Mn, 0.03 per cent S, 0.03 per cent P, and 0.25 per cent Ni. Since completing this work our attention was called to other Enduro products, such as Enduro 18-8, a chromium-nickel steel. The present experiment refers to Enduro Type "A" only.

The solutions used consisted of 4 organic acids, 2 mineral acids, sweet and sour milks and creams, and sour cream neutralized, as shown in tables 1 and 3.

Method of procedure. The corrosion tests on the metal strips were conducted by immersing them in the liquids tested to the extent of one-half of their length, making it possible to observe the effect at the air-liquid line. Other strips of the same metals, only 2 inches long, were used for total immersion. Additional short strips were provided with rivets of other metals in order to study the effect of metals with different electrical potentials in contact with one another.

In all cases half-pint Mason jars with glass covers were used. Each jar contained 130 cc. of the liquid under test. This made possible submersion of one-half of the length of the strips in each case. The metal strips were cleaned by washing in a very dilute solution of tri-sodium phosphate. They were then thoroughly rinsed in water, wiped dry, dried in a vacuum oven and carefully weighed. After immersing the strips in the respective liquids the jars containing liquid and strip were sealed and held at the temperatures indicated in table 3. At the end of the test period, the metal strips were removed and again washed, rinsed, dried, and weighed as before.[1] The strips were examined for visible corrosion and the liquids for color, precipitate, and flavor, and in some instances for metallic salts. In the case of complete submersion of the metal strips the procedure was identical with that described above, with the exception that the strips were only one-half the length of those used in partial immersion.

METALS IN ACID SOLUTIONS

The acids used were 1 per cent solutions of acetic, butyric, lactic, hydrochloric, and sulphuric acids, and 0.2 per cent solutions of citric acid. Solutions of such weak organic acids as lactic, butyric, citric, and acetic, usually encountered in milk products, were included in these tests chiefly for the purpose of determining the character and extent of action of the acids themselves, and of thus revealing what acids, if any, are most harmful and to what extent the non-acid constituents and other substances present in the dairy product cause corrosion of the metals.

The two mineral acids—sulphuric and hydrochloric—were included chiefly to determine the limit of resistance to corrosion of the several metals.

Results obtained in acid solutions. The weight losses or gains per metal strip are assembled in table 1. They are expressed in milligrams. The area submerged in the acid solution totaled

[1] The strips were washed and dried in the above manner, rather than by the use of alcohol and ether, to facilitate removal of curdy material. This procedure proved justifiable as the result of numerous preliminary tests which demonstrated absence of noticeable change in weight.

approximately 5.5 square inches. In some instances there was considerable oxidation of the metal above the liquid. This may at times have tended to partly offset the weight losses due to corrosion of the submerged portion. All increases in weight are indicated by a plus (+) sign.

Table 2 describes the appearance of the strips. In some cases the strips were merely tarnished, in others they were corroded or pitted. The effect on the metal at the air-liquid line was quite pronounced in some instances. Thus many of the iron strips corroded most severely just at the surface of the liquid, and in the case of hydrochloric, sulphuric, and acetic acids the strips were deeply etched at the air-liquid line. On the galvanized iron strips, too, corrosion appeared most pronounced right at the surface of the liquid.

In some of the acid solutions considerable white precipitate was present. This was especially noticeable with tin, tinned copper, and tinned iron immersed in sulphuric, acetic, and lactic acids. In the case of Ascoloy and Enduro a very heavy green precipitate resulted in sulphuric acid. No such precipitate appeared with Allegheny Metal.

The organic acid solutions were tasted for presence of metallic flavor wherever possible. Very definite metallic flavor was found in the solutions exposed to the iron and copper strips, and a metallic flavor could be noted in case of the imperfectly tinned iron. In the solutions containing the galvanized iron and zinc, respectively, the acidity had become pronouncedly less, and a sweetish, metallic character could be noted. A slight metallic flavor also was evident in the case of Monel Metal in citric acid.

Discussion of results shown in tables 1 and 2. As was to be expected, the stronger the acids the more intense their action on the metals. In the case of the organic acids, however, those metals which were attacked by lactic acid were affected almost equally as severely by the other organic acids used, even by weak solutions of citric acid.

These tests gave convincing proof of the great resistance of Allegheny Metal to corrosion. This alloy suffered practically no weight loss nor did it show visible corrosion in any of the acids

except hydrochloric. In the weaker organic acids, such as lactic, acetic, butyric, and citric, the ordinary chromium steels, Ascoloy

TABLE 1

Loss in weight of metal strips in acid solutions; partial immersion

METALS	1 PER CENT HYDROCHLORIC ACID, 5 DAYS 70°F.	1 PER CENT SULPHURIC ACID, 5 DAYS 70°F.	1 PER CENT ACETIC ACID, 5 DAYS 70°F.	1 PER CENT BUTYRIC ACID, 5 DAYS 70°F.	1 PER CENT LACTIC ACID, 5 DAYS 70°F.	0.2 PER CENT CITRIC ACID, 5 DAYS 70°F.	1 PER CENT BUTYRIC ACID, 5 HOURS 145°F.	1 PER CENT LACTIC ACID, 5 HOURS 145°F.
	mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
Single metals:								
Aluminum	404.5	17.8	0.5	2.1	0.4	0.3+	5.6	3.8
Copper	257.9	50.0	48.3	30.1	26.4	26.0	8.2	5.5
Iron	352.5	314.8	417.4	258.6	261.8	200.0	200.2	202.1
Nickel	28.3	55.5	23.3	5.7	34.4	34.0	3.9	5.7
Tin	91.7	27.8	24.3	0.5+	32.9	32.5	0.3	7.2
Zinc	1,200.0	884.7	83.8	75.7	212.9	88.0	8.9+	14.8
Plated metals:								
Copper, tinned E. B.*	56.9	24.0	44.2	2.1	50.8	57.0	1.2	7.1
Copper, tinned E. T.†	142.0	22.2	46.9	23.2	53.1	48.5	7.1	9.0
Copper Retin	89.3	30.3	31.6	2.3	134.4	37.8	0.2	7.4
Iron, galvanized	718.6	701.8	650.7	486.5	467.9	136.1	183.2	486.1
Iron, tinned E. B.*	97.6	65.2	93.8	52.3	51.5	47.4	11.7	11.5
Iron, tinned E. T.†	109.6	55.5	63.8	14.6	47.7	27.0	5.0	17.3
Al. alloy, Al. plated	28.7	15.2	0.6	5.9	0.4	0.0	3.8	2.4
Alloys:								
Ascoloy	955.2	653.7	0.0	0.6	0.0	0.5	0.0	0.3+
Allegheny Metal	24.5	0.3	0.0	0.9	0.0	0.5	0.4+	0.0
Enduro	943.1	639.1	0.8	1.5	0.2	2.0	0.6	0.4+
Monel metal	54.9	38.6	29.8	16.7	24.7	20.0	5.7	5.0
Nickel silver	151.6	41.6	26.0	16.5	5.7	16.5	6.7	3.5
Mn. Al. alloy	589.7	16.3	1.0	1.5	0.7	0.0	5.0	4.2

* E. B. designates that the strips were tinned in such a way as to leave the edges bare. This was to represent a condition of imperfect tinning.

† E. T. designates that the strips were completely tinned, edges and all.

\+ indicates gain in weight.

TABLE 2

Appearance of metal strips after immersion in acid solutions; partial immersion

METALS	1 PER CENT HYDROCHLORIC ACID, 5 DAYS, 70°F.	1 PER CENT SULPHURIC ACID, 5 DAYS, 70°F.	1 PER CENT ACETIC ACID, 5 DAYS, 70°F.	1 PER CENT BUTYRIC ACID, 5 DAYS, 70°F.	1 PER CENT LACTIC ACID, 5 DAYS, 70°F.	0.2 PER CENT CITRIC ACID, 5 DAYS, 70°F.	1 PER CENT BUTYRIC ACID, 5 HOURS, 145°F.	1 PER CENT LACTIC ACID, 5 HOURS, 145°F.
Single metals:								
Aluminum	t / ccc	O.K. / cc	t / O.K.	O.K. / c	O.K. / c	O.K. / c	t / c	tt / cc
Copper	tt / ccc	t / cc	ttt / cc	tt / cc	t / cc	t / ccc	tt / cc	ttt / cc
Iron	cc / cccc	c / cccc	ccc / ccc	cc / ccc	ccc / ccc	cc / ccc	cc / ccc	c / ccc
Nickel	O.K. / cc	O.K. / cc	t / tt	O.K.	O.K. / tt	O.K. / t	O.K. / t	O.K. / tt
Tin	t / cc	O.K. / cc	O.K. / cc	O.K. / t	O.K. / cc	O.K. / cc	O.K. / t	O.K. / cc
Zinc	c / cccc	c / cccc	ccc / c	cc / ct	O.K. / c	t / c	cc / ct	tt / c
Plated metals:								
Copper, tinned E. B.	O.K. / ccc	O.K. / ccc	t / cc	O.K. / t	O.K. / ccc	O.K. / cc	O.K. / t	t / cc
Copper, tinned, E. T.	t / ccc	O.K. / ccc	t / cc	O.K. / tt	O.K. / cc	O.K. / cc	O.K. / t	t / cc
Copper Retin	O.K. / ccc	O.K. / ccc	O.K. / cc	O.K. / t	O.K. / ccc	O.K. / cc	t / t	O.K. / cc
Iron, galvanized	c / cccc	c / ccc	ccc / ccc	cc / cct	c / cc	O.K. / cct	c / c	c / ccc
Iron, tinned E. B.	c / ccc	c / ccc	cc / ccc	c / c	O.K. / ccc	O.K. / cc	O.K. / c	t / cc
Iron, tinned E. T.	c / ccc	c / ccc	cc / ccc	c / c	c / ccc	c / cc	O.K. / c	t / cc
Al. alloy, Al. plated	t / cc	O.K. / cc	t / O.K.	t / O.K.	O.K. / c	O.K.	tt / c	O.K. / c

O.K. = no change.

c = slightly corroded, cc = corroded, ccc = heavily corroded, cccc = very heavily corroded.

t = slightly tarnished, tt = tarnished, ttt = heavily tarnished.

The condition of the strip above and below the air-liquid line is indicated by the position of the key letter above or below the dash. Thus, tarnished above and corroded below the air-liquid line is indicated as follows: $\frac{tt}{cc}$, heavily tarnished above and heavily corroded below $\frac{ttt}{ccc}$, etc.

TABLE 2—*Continued*

METALS	1 PER CENT HYDROCHLORIC ACID, 5 DAYS, 70°F.	1 PER CENT SULPHURIC ACID, 5 DAYS, 70°F.	1 PER CENT ACETIC ACID, 5 DAYS, 70°F.	1 PER CENT BUTYRIC ACID, 5 DAYS, 70°F.	1 P.ER CENT LACTIC ACID, 5 DAYS, 70°F.	0.2 PER CENT CITRIC ACID, 5 DAYS, 70°F.	1 PER CENT BUTYRIC ACID, 5 HOURS, 145°F.	1 PER CENT LACTIC ACID, 5 HOURS, 145°F.
Alloys:								
Ascoloy	t / ccc	t / ccc	O.K.	O.K.	O.K.	O.K.	O.K.	O.K. / t
Allegheny Metal	O.K. / c	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.
Enduro	t / ccc	t / ccc	O.K.	O.K.	O.K.	O.K. / t	O.K.	t / O.K.
Monel Metal	t / cc	O.K. / cc	O.K. / c	c	c	cc	c	O.K. / c
Nickel silver	t / ccc	tt / cc	ttt / cc	cc / O.K.	c / t	O.K. / cc	ttt / O.K.	tt / t
Mn. Al. alloy	t / ccc	O.K. / cc	t / O.K.	O.K. / c	O.K. / c	O.K.	tt / c	O.K. / c

and Enduro, resisted the action of the acid nearly as completely as Allegheny Metal. Where there was any noticeable difference in appearance it was limited to a barely perceptible brightening of the surface below the air-liquid line when holding the strips at a certain angle in the light, otherwise there was no evidence of visible corrosion on these three steel alloys. The weight losses here were very small, in only two instances did they exceed 1 mgm.

In sulphuric and hydrochloric acid solutions, however the ordinary chromium steels failed to stand up. They rusted and pitted profusely and lost over 600 mgm. in sulphuric and over 900 mgm. in hydrochloric acid. This represents losses of 110 and 180 mgm., respectively, per square inch. This suggests that when corrosion in these ordinary stainless steel products once starts, it proceeds rapidly. Allegheny Metal, on the other hand, resisted the action of such weak sulphuric acid solutions completely, showing not the slightest discoloration and the loss in weight was only 0.3 mgm. It should be pointed out here, however, that this refers to cold 1 per cent solutions only and does not indicate what might occur in stronger solutions and in

the presence of heat. In hydrochloric acid this alloy did suffer attack and some loss in weight, but the action was less intense than in the case of any of the other metals and alloys under investigation.

Next to the chromium steels, aluminum and manganese aluminum alloy resisted corrosion in the cold organic acid solutions best. In the heated solutions, however, the strips of the aluminum products showed more intense corrosion and greater loss in weight. The general tendency seems to be that the aluminum plated alloy resisted action more than the other aluminum products. This was especially noticeable in the appearance of the metal strips. In sulphuric acid the aluminum products also stood up better than any metal outside of Allegheny Metal, although they suffered considerable corrosion and loss in weight. In hydrochloric acid, however, aluminum and manganese aluminum alloy failed to show resistance. They lost about 100 mgm. per square inch. The aluminum plated alloy here again was attacked the least, and ranked second best to Allegheny Metal.

Following the chromium steels and the aluminum group in point of resistance to weak organic acids are nickel, tin, Monel Metal, and nickel silver. Of these four, nickel, closely followed by tin, appeared to be superior to Monel Metal and nickel silver from the standpoint of visible corrosion and tarnishing. This group shows considerably greater loss in weight than the previous groups. It is especially noticeable that nickel and tin lost most heavily in acetic, lactic, and citric acid solutions, but resisted butyric acid considerably better. Monel Metal and nickel silver, on the other hand, suffered material loss in butyric acid but less in lactic and citric acid than nickel and tin. Taking the total losses in all organic acid solutions into consideration, nickel and Monel Metal lost most, tin next, and nickel silver least of this group. In this comparison it was at first thought that the heavier tarnishing of the nickel silver may have been a factor in partly offsetting loss in weight. However, our results with total submersion do not bear out this assumption, as here the weight losses of nickel silver were even less than in the case of half immersion. In the mineral acids the corrosion and loss in weight was generally

greater than in the organic acids. Nickel suffered less in hydrochloric acid than in sulphuric acid, while tin, Monel Metal, and nickel silver were attacked more intensely by the hydrochloric acid than by the sulphuric acid.

Falling into the next group we find tinned copper, copper, and tinned iron. The visible corrosion on all of these was much greater than in the previous groups, and the loss in weight had also materially increased. In the case of the tinned iron, some rusting through the tin coating was in evidence, indicating imperfection in the tin coat on the iron. In butyric acid solutions the tinned copper and tinned iron closely followed tin in resistance, i.e., they suffered much less loss in weight and showed less visible corrosion here than in the other organic acids. In the case of copper strips the submerged part even in the weakest organic acid solutions showed marked brightening of the surface, an unmistakable evidence that the copper was severely attacked and going into solution. The portion of the copper above the liquid was tarnished heavily, evidently due to the formation of copper oxides.

To the group showing the least resistance to corrosion in these weak organic acids belong galvanized iron, iron, and zinc. Of these, galvanized iron suffered by far the greatest loss in weight. These three metals showed very severe corrosion in all the acids used. It is of particular interest here that these metals showed very heavy corrosion above the liquid in the case of acetic and butyric acids.

The trend of corrosion in the mineral acids was similar to that in the organic acids, the rate of corrosion, however, being much greater in most cases. As might be expected, zinc, galvanized iron, and iron showed the least resistance and, as previously stated, the ordinary chromium steels, Ascoloy and Enduro, also rusted profusely and lost heavily in weight. In all cases except nickel, the corrosion was much greater in hydrochloric acid than in sulphuric acid.

METALS IN MILK AND CREAM

In the study of the effect of metals in milk and cream, as wide a variety of dairy products as is usually encountered in commercial

plant operation was used. With this in mind, fresh sweet milk and cream, sour milks of varying acidities and sour gathered cream, both unneutralized and neutralized were included.

The sweet milk tested from about 3 to 3.5 per cent fat with an acidity of 0.16 per cent acid or below. Several different types of sour milks were chosen, such as ordinary creamery buttermilk ranging in acidity from 0.29 per cent at the churn to approximately 0.85 per cent acid at the conclusion of the metal test; butter culture consisting of fresh whole milk ripened by inoculation with a mixed culture of *S. lactis* and *S. citrovorus* to an acidity of 0.83 per cent; and acidophilus milk consisting of fresh whole milk, inoculated and ripened with a pure culture of *L. acidophilus* to 1.76 per cent acid. In both the butter culture and the acidophilus milk the metal strips were immersed in the original sweet milk and kept in the liquid during the preparation, ripening, and holding of these products. The cream, both sweet and sour, was direct shipper cream averaging approximately 35 per cent fat. The sweet cream tested from 0.11 to 0.14 per cent acid at arrival and 0.16 to 0.25 per cent at the conclusion of the holding period. The sour cream, upon arrival at the factory, tested from 0.5 to 0.6 per cent acid and was then ripened without culture to an acidity of 1 per cent. This was done to simulate severe summer conditions. Two different periods of exposure and temperatures were used, namely five hours at 145°F. and five days at room temperature (70°F.). In the case of neutralized cream, two sets of tests were made. In the first test the original sour cream was neutralized with calcium magnesium lime from 0.5 to 0.15 per cent acid. Then the metal strips were immersed and the cream was held at 145°F. for five hours. In the second set, the metal strips were immersed in the original cream, testing 0.5 to 0.6 per cent acid, just before neutralization. The cream was then neutralized with lime to 0.15 per cent acid, then pasteurized at 145°F. for thirty minutes, cooled to 45°F., and held overnight. The metal strips were then removed, washed, steamed, and the same procedure repeated daily for ten consecutive days. The acidities of the several lots of milk and cream at beginning and end of each test and the times and temperatures of exposure were as shown in table 3.

Tables 4, 5, 6, and 7 show the results obtained in milk and cream, sweet and sour, and hot and cold. Table 4 gives the weight losses and table 5 the visible corrosion of the metal strips; table 6 indicates the effect on the flavor of the dairy product. In table 7 are recorded the results obtained by exposing the metal strips to sour cream during neutralization, pasteurization, cooling and holding, daily for ten consecutive days with a fresh batch of cream each day as previously described under materials used.

Discussion of results shown in tables 4, 5, 6 and 7. In general it was noted that where the metal was able to resist corrosion in

TABLE 3

Temperature, acidity, and period of exposure of milks and creams

DAIRY PRODUCTS	PERIOD HELD	TEMPERATURE	ACIDITY AT BEGINNING	ACIDITY AT END
		°F.	*per cent*	*per cent*
Sweet milk	5 days	70	0.14–0.15	0.26–0.32
Sweet milk	5 hours	145	0.15	0.15
Sweet cream	5 days	70	0.14	0.25
Sweet cream	5 hours	145	0.14	0.16
Buttermilk	5 days	70	0.29	0.82–0.87
Butter culture	15 hours	70	0.16	0.83
	30 hours	40		
Acidophilus	5 days	98	0.16	1.76
Sour cream	5 days	70	1.00	1.00
Sour cream	5 hours	145	1.00	1.00
Sour cream neutralized	5 hours	145	0.15	0.15
Sour cream neutralized	Factory procedure, daily for 10 days		From about 0.6 to about 0.15	

weak organic acid solutions it was likewise not seriously affected by milk and cream, and did not produce objectionable flavors in these products. This would indicate that the highly complex colloidal nature of the dairy product apparently did not alter the general resistance of the metal to corrosion by acids. In fact, the corrosion in the cream containing 1 per cent acid was less intense than in the 1 per cent lactic acid solution, suggesting that the non-acid constituents tend to exercise a protective influence.

Effect of milk and cream on the metals. As shown in tables 4, 5, and 7 the corrosion and loss of weight of the metal strips and the

TABLE 4

Loss in weight of metal strips in sweet and sour milks and creams; partial immersion

METALS	SWEET MILK		SOUR MILKS			SWEET CREAM		SOUR CREAM		SOUR NEUTRALIZED CREAM
	70°F., 5 days, acid 0.15 per cent	145°F., 5 hours, acid 0.15 per cent	Acidophilus 98°F., 5 days, acid 1.76 per cent	Butterculture 70°F., 2 days, acid 0.83 per cent	Buttermilk 70°F., 5 days, acid 0.29 to 0.87 per cent	70°F., 5 days, acid 0.16 per cent	145°F., 5 hours, acid 0.16 per cent	70°F., 5 days, acid 1.0 per cent	145°F., 5 hours, acid 1.0 per cent	145°F., 5 hours, acid 0.15 per cent
	mgm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
Single metals:										
Aluminum	0.7+	0.1	1.0	0.0	0.1	0.7	0.1+	1.1+	0.6	0.7
Copper	1.1	1.8	4.6	1.9	7.2	4.0	2.4	3.5	3.3	1.0
Iron	24.2	4.6	179.6	62.3	147.6	0.0	5.1	127.6	72.8	2.5
Nickel	2.6	1.2	14.6	4.3	6.4	5.4	2.4	3.9	2.7	0.0
Tin	2.7	0.5	4.4	0.8	2.6	0.3	0.8	1.1	0.5	0.8
Zinc	3.6	0.1	41.1	5.0	21.0	1.2	1.4	18.3	8.8+	5.0
Plated metals:										
Copper, tinned E. B.*	0.4	0.6	4.8	0.6	0.3	1.5	0.3+	1.4	1.6	0.2
Copper, tinned E. T. †	0.0	0.7+	4.3	3.5	3.4	1.0	0.1+	2.8	1.3	0.1
Copper Retin	2.5	0.1	0.9	0.4	1.7	0.3+	0.8	0.5	0.8	1.1
Iron, galvanized	21.2	0.3	447.2	9.6	41.6	9.9+	0.9+	1.0+	17.7	2.4
Iron, tinned E. B.	3.7	0.7+	6.0	2.2	15.7	2.9	0.3	6.4	5.0	1.0
Iron, tinned E. T.	0.3	0.1	4.9	0.8	3.6	1.2	0.1	7.2	3.9	1.8
Al. alloy, Al. plated	0.9+	0.8	1.2	0.0	0.2	0.0	0.5+	1.2+	0.6	0.3

Alloys:										
Ascoloy	0.1	0.9+	1.3	1.4	0.0	0.1	0.6	1.4	0.4	0.4
Allegheny Metal	0.2	0.8+	0.7	1.4	0.0	0.4	0.0	1.3	0.5+	0.4
Enduro	0.0	1.1+	0.7	1.3	0.0	1.3	0.4+	1.0	0.3	0.7+
Monel Metal	1.3	0.5	7.3	1.9	2.2	2.1	0.3	2.8	1.4	0.3
Nickel silver	3.3	1.2	9.9	3.0	3.2	4.1	2.8	5.0	1.9	0.3
Mn. Al. alloy	0.4+	0.5+	1.5	0.4	0.9	1.4	0.5+	0.3+	1.1	0.4

* E. B. designates that the strips were tinned in such a way as to leave the edges bare. This was to represent a condition of imperfect tinning.

† E. T. designates that the strips were completely tinned, edges and all.

+ indicates gain in weight.

TABLE 5

Appearance of metal strips after immersion in dairy products; partial immersion

METALS	SWEET MILK		SOUR MILKS			SWEET CREAM		SOUR CREAM		SOUR NEUTRALIZED CREAM
	70°F., 5 days, acid 0.15 per cent	145°F., 5 hours, acid 0.15 per cent	Acidophilus 98°F., 5 days, acid 1.76 per cent	Butterculture 70°F., 2 days, acid 0.83 per cent	Buttermilk 70°F. 5 days acid 0.29 to 0.37 per cent	70°F., 5 days, acid 0.16 per cent	145°F., 5 hours, acid 0.16 per cent	70°F., 5 days, acid 1.0 per cent	145°F., 5 hours, acid 1.0 per cent	145°F., 5 hours, acid 0.15 per cent
Single metals:										
Aluminum	O.K.	tt / O.K.	tt / c	O.K.	O.K.	O.K.	O.K.	O.K.	O.K. / c	t / t
Copper	O.K. / cc	ttt / cc	tt / ccc	tt / cc	tt / ccc	t / cc	tt / cc	tt / cc	tt / cc	tt / cc
Iron	c / t	c / t	ccc / ccc	ccc / cc	c / ccc	cc / tt	c / tt	ccc / ccc	ccc / cc	c / tt
Nickel	O.K. / tt	O.K. / tt	O.K. / cct	O.K. / ttt	O.K. / c	O.K. / ttt	O.K. / t	O.K. / t	O.K. / t	O.K. / ttt
Tin	O.K. / t	O.K.	O.K. / tt	O.K.	t / t	O.K. / t	O.K.	O.K.	O.K. / t	tt / tt
Zinc	c / cc	t / cc	cc / ccc	tt / cc	cc / cc	cc / cc	c / cc	cc / cc	cc / cc	ttt / cc
Plated metals:										
Copper, tinned E. B.	O.K.	t / O.K.	t / c	t / cc	O.K.	c / c	tt / tt	O.K. / c	O.K. / c	t / ct
Copper, tinned E. T.	O.K.	O.K.	t / c	t / c	O K.	t / c	t / O.K.	O.K. / c	O.K. / c	t / ct
Copper Retin	t / c	O.K.	t / O.K.	O.K.	O.K. / c	O.K.	t / O.K.	O.K.	t / O.K.	t / O.K.

Plated metals—continued:										
Iron, galvanized	c / cc	t / c	cc / ccc	cc / c	c / cc	cc / c	c / O.K.	c / cc	cc / cc	tt / cc
Iron, tinned E. B	t / O.K.	t / O.K.	cc / cc	O.K.	c / O.K.	t / O.K.	O.K. / t	c / O.K.	cc / c	t / O.K.
Iron, tinned E. T	cc / O.K.	O.K.	cc / c	c / c	c / c	O.K. / c	O.K. / c	c / c	cc / c	c / c
Al. alloy, Al. plated	O.K.	O.K.	t / c	O.K.	O.K.	O.K.	t / O.K.	O.K. / t	t / c	t / t
Alloys:										
Ascoloy	O.K.	O.K.	O.K. / c	O.K.	O.K.	O.K.	O.K.	O.K.	O.K. / t	O.K. / t
Allegheny Metal	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.
Enduro	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	t / O.K.	O.K.
Monel Metal	O.K. / ttt	O.K. / ttt	O.K. / ttt	O.K. / ttt	O.K. / tt	O.K. / t	O.K. / tt	O.K. / tt	O.K. / tt	O.K. / tt
Nickel silver	t / ttt	t / tt	cc / ttt	tt / tt	tt / ttt	t / tt	t / t	ttt / ttt	ttt / t	tt / t
Mn. Al. alloy	O.K.	O.K.	tt / c	O.K.	O.K.	O.K.	tt / O.K.	O.K. / t	t / c	O K. / t

TABLE 6

Flavor of sweet and sour milks and creams; partial immersion

METALS	SWEET MILK		SOUR MILKS			SWEET CREAM		SOUR CREAM		SOUR NEUTRALIZED CREAM
	70°F., 5 days, acid 0.15 per cent	145°F., 5 hours, acid 0.15 per cent	Acidophilus 98°F., 5 days, acid 1.76 per cent	Butter-culture 70°F., 2 days, acid 0.83 per cent	Buttermilk 70°F., 5 days, acid 0.29 to 0.87 per cent	70°F., 5 days, acid 0.16 per cent	145°F., 5 hours, acid 0.16 per cent	70°F., 5 days, acid, 1.0 per cent	145°F., 5 hours, acid 1.0 per cent	145°F., 5 hours, acid, 0.15 per cent
Single metals:										
Aluminum			Sl. Met.	Sl. Met.						
Copper	Tallowy	Sl. Met.	Sl. Met.	Metallic	Green Whey	Tallowy	V. Met.	Metallic	Metallic	Sl. Met.
Iron	Metallic	V. Met.	V. Met.	V. Met.	Metallic	V. Met.	V. Met.	V. Met.	V. Met.	Sl. Met.
Nickel			Sl. Met.	Sl. Bitter		Sl. Bitter	Sl. Met.			
Tin										
Zinc			V. Met.	Metallic	Sl. Met.				Sweetish	Metallic
Plated metals:										
Copper, tinned E. B.				Sl. Met.		Bitter	Sl. Off		V. Met.	
Copper, tinned E. T.						Bitter				
Copper Retin										
Iron, galvanized	Fishy	Metallic	V. Met.	Metallic	Metallic		Sl. Off	Bitter	Sl. Bitter	Metallic
Iron, tinned E. B.			V. Met.	V. Met.	Metallic	Sl. Met.			Metallic	Sl. Met.
Iron, tinned E. T.		Metallic	Sl. Met.	Sl. Met.		Bitter			Metallic	Sl. Met.
Al. alloy, Al. plated				Sl. Met.					Metallic	
Alloys:										
Ascoloy			Metallic							
Allegheny Metal										
Enduro			Metallic							
Monel Metal				Sl. Met.			Off			
Nickel silver		Sl. Met.	Sl. Met.	Metallic			Metallic		Sl. Met.	
Mn. Al. alloy							Sl. Met.			

V. = very; Sl. = slightly; Off = off flavor.

TABLE 7

Neutralized cream treatment simulating factory operation

Strips exposed to sour cream (0.5 to 0.6 per cent) neutralized to 0.15 per cent, pasteurized at 145°F., held thirty minutes, cooled to 45°F., held overnight. Treatment repeated daily for ten consecutive days, using a fresh batch of cream each day.

Total loss from first to last treatment

METALS	AFTER FIRST TREATMENT		AFTER THIRD TREATMENT		WEIGHT LOSS				TENTH TREATMENT	
	Weight loss	Flavor	Weight loss	Flavor	5th	6th	7th	8th	Weight loss	Flavor
	mgm.		*mgm.*		*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
Single metals:										
Aluminum	0.2	O.K.	0.3	O.K.	1.0	1.3	0.7	0.4	0.7	O.K.
Copper	2.1	Sl. Met.	3.1	O.K.	5.9	7.1	6.9	6.5	7.0	Sl. Met.
Iron	4.0	Met.	23.4	Met.	37.8	44.3	47.7	49.8	59.1	Met.
Nickel	2.1	O.K.	4.6	O.K.	7.0	7.0	7.7	8.4	9.9	O.K.
Tin	0.6	O.K.	1.5	O.K.	1.8	2.1	1.4	1.4	1.9	O.K.
Zinc	2.3	V. Met.	2.5	Sl. Met.	3.0	15.4	18.8	20.7	25.4	Sl. Met.
Plated metals:										
Copper, tinned E. B.	0.4	O.K.	1.0	O.K.	1.3	0.8	1.0	1.1	1.8	O.K.
Copper, tinned E. T.	0.5	O.K.	5.0	Sl. Met.	5.6	5.5	5.5	5.6	6.5	O.K.
Copper Retin	0.5	O.K.	0.6	O.K.	1.4	1.7	1.1	1.0	1.1	O.K.
Iron, galvanized	1.1+	V. Met.	2.1	Met.	44.6	44.1	43.0	44.9	48.4	Sl. Met.
Iron, tinned E. B.	0.6	V. Met.	2.8	Met.	6.1	6.4	5.8	6.5	8.7	Sl. Met.
Iron, tinned E. T.	1.2	O.K.	2.2	O.K.	3.5	4.6	3.4	3.8	4.7	Sl. Met.
Al. alloy, Al. plated	0.4	O.K.	0.0	O.K.	0.5	2.1	0.7	0.4	0.9	O.K.
Alloys:										
Ascoloy	0.0	O.K.	0.6	Sl. Met.	0.7	0.9	0.2	0.4	0.4	O.K.
Allegheny Metal	0.0	O.K.	0.8	O.K.	0.7	0.5	0.1	0.0	0.1	O.K.
Enduro	0.6+	O.K.	1.2+	O.K.	0.5+	0.5+	1.2+	0.7+	0.1+	O.K.
Monel Metal	0.8+	O.K.	0.0	O.K.	0.6	1.3	1.3	1.2	1.4	O.K.
Nickel silver	0.8	Sl. Met.	2.7	O.K.	3.9	3.9	3.8	4.0	5.1	O.K.
Mn. Al. alloy	0.4	O.K.	0.5	O.K.	0.7	1.3	0.6	0.4	0.6	O.K.

+ indicates gain in weight.

Met. indicates metallic flavor; Sl. Met., slightly metallic; V. Met., very metallic; O.K., no off flavor.

order of their resistance are in the general direction indicated by the results in weak organic acid solutions as previously given in tables 1 and 2, though the intensity of corrosion in the dairy products is markedly less.

Thus iron, galvanized iron, and zinc again were poorest, and showed the least resistance, as indicated both by the visible corrosion on the strips and by the weight losses recorded, while the chromium steels and aluminum products withstood attack most successfully. Tin and tinned copper also showed comparatively high resistance. Nickel, copper, Monel Metal and nickel silver suffered rather severe tarnishing and considerable loss in weight, particularly in the high acid milk products.

Comparison between sweet and sour liquids indicates, with very few exceptions, more severe action in the sour liquids. This again emphasizes that acidity in milk products is the dominating factor in corrosion directly due to contact with dairy products. But even in the sweet milk products many of the metals showed marked tarnishing and some corrosion. This was particularly noticeable in the case of nickel, nickel silver, and Monel Metal.

It is further interesting to note that in the neutralized sour cream exposed to 145°F. for five hours, tables 4 and 5, all metals showed comparatively high resistance, with the possible exception of iron, galvanized iron, zinc, and copper. In the neutralized sour cream, table 7, in which the metal strips were immersed just before neutralization and the treatment was repeated daily for ten consecutive days, however, the intensity of corrosion was greatly augmented. The attack on iron, galvanized iron, and zinc here again was by far the most severe, but nickel, copper, tinned iron, and nickel silver also suffered very considerable loss in weight. Tin proved relatively resistant. The tinned copper surfaces also held up well, except in one case where the loss was almost equal to that of copper. This suggests that the resistance of the tinned metal is dependent very greatly on the quality of the tinning. This may also help to explain the comparatively heavy loss in weight of the tinned iron strips, due probably to the greater porosity of the tin coating on iron.

The above experiment was conducted in such a way as to

expose the metals daily to a new batch of cream for ten consecutive days. The treatment given was similar to that in commercial plant operation. It appears justifiable to assume that these metals would show approximately the same order of resistance in large-scale, commercial equipment.

Effect of the metals on milk and cream. Each sample of cream was carefully graded, especially for metallic flavor, by several independent judges after the strips were removed from the test.

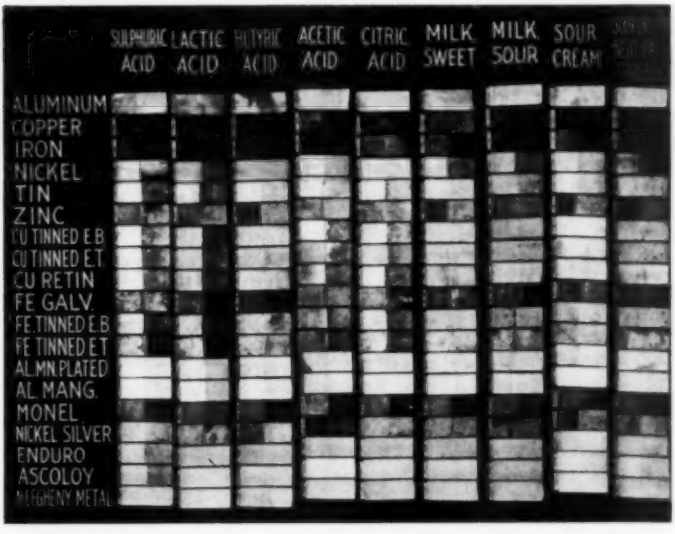

FIG. 1. SETS OF METAL STRIPS AFTER HALF IMMERSION IN THE LIQUIDS LISTED AT THE TOP

These results are shown in tables 6 and 7. In some cases, such as sour cream held at room temperature for five days, other changes had taken place making it very difficult to recognize the metallic taste. Iron, copper, and galvanized iron, however, even here left such extremely metallic flavor that there was no difficulty in readily recognizing them. In all the other milks and creams the metallic or other characteristic flavors due to metallic action could be easily detected. On the whole, however,

the results obtained with butter culture were found the most reliable, as even delicate shades of off-flavor seemed to stand out definitely. Thus, in the latter case, i.e., with butter culture, our results show iron and tinned iron with the edges untinned to produce the most decided metallic flavor. Copper, zinc, galvanized iron and nickel silver also gave the butter culture a distinct metallic taste. Aluminum, nickel, copper tinned with edges not tinned, iron completely tinned, manganese aluminum alloy plated, and Monel Metal developed a slight metallic flavor. The remaining metals and alloys, namely tin, completely tinned copper, manganese aluminum alloy, and the chromium steels, failed to have any effect on the flavor of the culture. It will be noted that in the case of this milk product the metal strips remained in the milk during every step in the preparation of the culture, to the end of the test which totaled in all two days, and that the acidity developed during this period from 0.16 to 0.83 per cent.

Because of the outstanding importance of the effect of the various metals on the flavor of the dairy products it is deemed desirable to discuss the results obtained somewhat in detail, grouping the metals according to their action on flavor.

Allegheny Metal, tin, and tinned copper. Allegheny Metal, tin, and completely tinned copper were the only metals that produced no metallic flavor in any of the milk products.

Allegheny Metal, the chromium-nickel steel alloy, showed no visible corrosion in the dairy products and there was practically a complete absence of loss in weight. Where such losses did occur they were invariably exceedingly small and apparently of no significance. In fact, Allegheny Metal ranked best of any of the metals under study. Where there was absence of corrosion in the case of several of the other metals, this alloy invariably also proved entirely immune. In liquids (acid solutions) and under treatment that caused serious corrosion of the other metals, Allegheny Metal was either not affected at all, or led the list in point of resistance to such corrosion. In only one instance did Allegheny Metal show visible attack. This was its exposure to hydrochloric acid and here again the corrosion was much less

than that of the other metals, with the exception of aluminum plated alloy and nickel, which lost only slightly more in weight than Allegheny Metal. In no case did Allegheny Metal injure the flavor of the milk product.[2]

This absence of corrosion suggests absence of solution of the metal. Since the development of metallic flavor depends upon solution of the metal and presence of the dissolved metal in the product, the complete absence of metallic flavor in all the milk products tested, i.e., exposed to Allegheny Metal, may be readily explained. These favorable qualities of Allegheny Metal emphasize its high desirability in dairy equipment and place it at the top of the list of metals studied in this experiment. In pointing out these superior qualities of Allegheny Metal, the nickel-chromium steel, attention should be called to the fact that this alloy differs from the ordinary chromium steels, or so-called stainless steels, in that the latter do not contain nickel and usually have a lower content of hromcium. The ordinary chromium steels, Ascoloy and Enduro, while showing high resistance to corrosion in most cases, did suffer slight attack under some conditions and in the case of acidophilus milk actually produced a metallic flavor.

These observations with Allegheny Metal are supported by the work of North (3). An analysis of his figures shows that Allegheny Metal ranked first and better than nickel and Enduro. Quam (4) also compared the resistance of these chromium steels and found Allegheny Metal far superior to the ordinary chromium steels. Grindrod (6), who, before the advent of Allegheny Metal in milk equipment, considered all-nickel and all-tin the only metals suitable, reports that Allegheny Metal has proven fully equal and in some respects superior to nickel in the construction and use of milk condensing and sterilizing equipment. Dahle (7) states that he used an Allegheny Metal tank repeatedly for making pure culture milk with an acidity of 1 per cent and

[2] It should be pointed out here that Allegheny Metal is but one representative of the general group of chromium-nickel-steel-alloys. At the inception of this investigation Allegheny Metal was the only product of this group then available to us. Other chromium-nickel steels of similar composition have since become available for the fabrication of dairy equipment.

noticed no spots nor discoloration on the metal, nor any off-flavors in the milk. MacQuigg (8) reports that high-chromium steels and chromium-nickel steels showed greater resistance to corrosion in the handling of corrosive chemicals than any other metal or alloy.

It is important, however, to call attention to the fact that Allegheny Metal is vulnerable and may suffer rusting and pitting when in contact, on the liquid side, with certain other metals. The attack here is caused by electrolysis and will vary in character and intensity with the electrical potential of the metal in contact. Users of Allegheny Metal tanks have learned that when such equipment contains rivets, bolts, fittings, or other accessories of such metals as iron, copper, nickel silver, Monel Metal, tin, etc., the resistance of the alloy to corrosion may be materially diminished and rust spots may appear. These findings support our results on multiplicity of metals in which the Allegheny Metal strips with iron rivets and tin rivets tarnished noticeably in some cases. Rusting may also occur on welded surfaces of Allegheny Metal in the absence of proper finishing of the weld, such as will remove all traces of iron oxide that may have formed during the welding process. As will be shown in a later paper, certain treatment with brine also has some effect on Allegheny Metal. Further observations emphasize that the maximum resistance to corrosion depends very much upon a high polish of the surface of the Allegheny Metal and that unpolished surfaces did yield some rusting.

Tin and properly tinned copper, as previously stated under this group heading, also failed to produce metallic flavor in any of the milk products. These metals, however, showed slight corrosion and considerable loss in weight in some instances. The weight losses of tin and properly tinned copper averaged slightly over twice as much as those of the chromium steels.

While the solubility of tin in the milk product is not inconsiderable, the salts of tin appear to cause no noticeable injurious effect on the flavor of the milk product. In the present experiment the pure tin proved entirely harmless in this respect. Under no condition, regardless of temperature, acidity, or time of

exposure of the milk product, was there the slightest suggestion of metallic or other objectionable off-flavor. These results are in harmony with the findings of Donauer (17), who shows that while tin is more soluble than copper and copper alloys, it required ten times as much tin in solution as it does copper to produce a distinct metallic flavor. That tin is incapable of inciting progressive decomposition and damage to flavor in butter while, under identical conditions, iron, copper, and nickel silver spoiled the butter entirely, bleaching it and making it intensely tallowy in flavor, was demonstrated by Hunziker and Hosman (9).

Further experimental proof of the action of weak organic acids on tin is cited by Mantell and Lincoln (10). These investigators studied the subject from the standpoint of the food canning industry and found that citric, lactic, and acetic acids attack tin and tin alloys. The life of the tin coating is further shortened by the excessive use of caustic alkali washing powders for cleaning, and hypochlorite solutions used for sterilizing the equipment.

Another possible contributing factor to the short life of the tin coating on copper may be the contamination of the tin with copper due to method of tinning. Thus, Merica (11) points out that in the usual method of tinning copper, the tin bath tends to become contaminated with copper and there is danger of obtaining a brittle tin coating.

All of these facts emphasize the great importance of a proper method of tinning copper and maintaining a complete tin coating on the copper surface. Manifestly, a complete and heavy tin coating of copper provides the most effective protection against the corrosion of copper and its damaging effect on the milk product. Properly tinned copper offers a safe surface for exposure to milk products. Tinned copper furnishes better protection in this respect than tinned iron. The life of the tin coating, however, is relatively short. At best, retinning at frequent intervals, therefore, becomes necessary in order to guard against the damaging effect of exposed copper. Even in such weak organic acid solutions as may be encountered in sweet and sour milk products, such as lactic, butyric, citric, and acetic acids, the corrosion and loss in weight was quite considerable. Tin, further-

more, is very soft so that the loss by friction and wear may be quite an important factor.

It appears pertinent here to suggest that improvement in the method of tinning leading to better contact and greater permanency of the tin coating on the copper surface, and possibly the hardening of the tin itself, are important problems, the satisfactory solution of which would eliminate some of the current objectionable features and would offer additional advantages to the user of tinned copper equipment.

The distinct absence of metallic flavor in dairy products held in contact with tin, together with the physical and fabrication advantages and the comparative ease of retinning, explain the continued popularity of tinned copper surfaces in dairy equipment, although the desirability of the presence in milk products of such metallic salts as the salts of tin may well be questioned.

Nickel. As far as the effect of nickel on the flavor of the milk product is concerned, the present experiment shows that nickel is not entirely negative. While no intense metallic flavor resulted from nickel in any of the milk products, a slight metallic and bitter flavor was noted in the case of acidophilus milk, butter culture, and in sweet cream, hot and cold. The ready solubility of nickel in weak organic acid solutions and in acidophilus milk suggest that nickel equipment is not so suitable for high-acid dairy products as has been generally assumed. In the milk products, table 4, and in the neutralized cream, table 7, the corrosion of nickel resulted in losses that averaged 3 and 5 times greater, respectively, than those for tin. Similar observations were also reported by Cornell (12), in his experiences with milk plants, who concludes that nickel is not so satisfactorily used in connection with the development of high-acid in dairy products. Burrell (5) reports that nickel hoops used for draining Camembert cheese were a failure and actually caused the cheese to turn green. Another manufacturer reported that a large all-nickel surface coil cooler installed in a city milk supply plant tarnished profusely and caused such serious discoloration of the milk that it was found necessary to tin plate the cooler, in order to prevent recurrence.

On the other hand, Grindrod (6) who worked with sweet milk, found that "evaporated milk made in all-nickel or all-tin apparatus was very far superior to the ordinary evaporated milk" (meaning that made in copper vacuum pans). Again, an all-nickel horizontal coil vat installed in one of the factories of the Blue Valley Creamery Company (13) was used for the pasteurization and ripening of cream. This vat has proved entirely satisfactory as far as its effect on the flavor of cream and butter is concerned. It has been in daily use for a period of over two years and at no time has there been any indication of metallic flavor in the milk product, although the nickel has lost its original luster, shows considerable tarnish, and analysis of the cream by Quam (14) disclosed the presence of appreciable quantities of dissolved nickel. Hunziker and Hosman (9) found nickel to be equally satisfactory as tin in protecting butter against progressive flavor deterioration. Prolonged contact of nickel with butter failed to produce metallic flavor in the butter.

As may be seen from the above references, experiences with all-nickel equipment in milk plant operation under widely varying conditions are somewhat at variance. The present experiment deals with the behavior of nickel in milk work and may, therefore, help to explain some of the varied experiences found in its actual use. Nickel showed considerable solubility in the milk acids and it tarnished easily in most of the milk products, as well as in the individual weak organic acid solutions. In a few instances only a slight metallic flavor was detected in the milk product (acidophilus milk and sweet cream). It is evident, therefore, that nickel cannot be considered immune from the standpoint of metallic action in milk products and yet, under average conditions, it may well be looked upon as a reasonably safe metal for milk work. Its ready tarnishing and its tendency to slightly affect the flavor in the case of high-acid milk products upon prolonged exposure, constitute its chief drawbacks. As will be shown under Combination of Metals, the tarnishing of the nickel can be practically avoided by the presence of aluminum fittings in all-nickel equipment. Nevertheless, since nickel is fairly soluble it appears pertinent, here as in the case of tin, to question the desirability

of the presence of considerable amounts of such metallic salts in food products.

Aluminum. Our results with aluminum suggest that this metal deserves favorable consideration in connection with milk plant equipment. With the exception of its instability in alkalies, as will be reported in a subsequent paper, its resistance to corrosion proved superior to tin and nickel products. In organic acids, sweet milk and cream, and moderately sour milk products, such as sour cream, buttermilk, and butter culture, corrosion and loss of weight were either entirely absent or only very slight. In dairy products of intensely high acidity, however, the corrosion was slightly more pronounced and a very slight metallic flavor was discernible. This was noticeable in high-acid milk, such as acidophilus milk.

The visible corrosion, tables 2, 5, and 7, was very slight. In most cases it was confined to a slight tarnish. This was noted chiefly in a few cases of high-acid milk and usually, but not always, in the presence of high temperature. The weight losses in the weak organic acids, table 1, while somewhat higher than those of the chromium steels, were far below those of any of the other metals. In the milk products, table 4, and in the neutralized cream experiment, table 7, the weight losses averaged practically the same as those for Allegheny Metal. The tendency to produce metallic flavor was no greater than in the case of nickel. There were no outstanding differences between the three aluminum products, i.e., pure aluminum, manganese-aluminum alloy containing 1.25 per cent manganese, and the same alloy plated with aluminum. The weight loss for each in the organic acids, the milk products, and the neutralized cream, averaged practically the same for all three metals, and no consistent difference could be observed in the visible corrosion of any of these three aluminum products nor in their effect on the flavor of the milk products.

It has been reported that in European milk plants where aluminum equipment is extensively used, because of its cheapness, the aluminum suffered considerable pitting in the presence of milk heated to high temperatures. These reports are not sup-

ported by observations by Hunziker (15) who has just visited numerous market milk plants in England, using aluminum pasteurizers, coolers, and holding tanks. This equipment had been in operation for a considerable time and showed no visible pitting nor objectionable tarnish. In the present experiment likewise, the aluminum products showed high resistance to corrosion and gave no evidence of pitting in milk and cream, hot or cold.

Another important factor greatly influencing the resistance of aluminum to corrosion in milk equipment is the physical state and purity of the metal. Thus, wrought aluminum, which is usually of relatively high purity, has been found to withstand attack far more readily than cast aluminum, which generally contains greater quantities of impurities. Seligman (1) points out that while tanks, cans, etc., made of sheet aluminum may be found unchanged after many years of use, cast fittings attached to the same containers may give out, after a few years' use. The cause of the short life of the cast metal in all probability lies in the presence of impurities, thus providing the necessary elements for the formation of electrical couples and giving rise to galvanic action. For similar reasons, contact of pure aluminum with other metals intensifies solution and pitting of aluminum, and as Seligman (1) suggests, the seriousness of the corrosion in such cases is intensified by the fact that the corrosion and pitting are often highly localized. In our own experiments aluminum rivets in nickel, Allegheny Metal, Ascoloy, and Enduro became markedly pitted and were partly eaten away. The aluminum rivets in tin were not affected. The relative softness of aluminum is an additional objection, particularly when subjected to rough handling. This suggests the advisability of heavy construction, especially in the case of large equipment. This objection is greatly decreased in the case of manganese-aluminum alloy which is a product of somewhat greater hardness as shown by Faragher (30).

These several drawbacks, while serious, may be readily minimized, if not entirely eliminated, by intelligent study of the properties of this metal and by suitable construction and proper

use of the equipment. The cheapness, lightness, and comparative inertness in contact with the milk product recommend its recognition in milk work in this country.

Chromium steels. As previously shown, the chromium steels studied in this experiment were of two types, namely, ordinary chromium steels, or straight-chromium irons, so-called stainless steels, such as Ascoloy and Enduro; and the special chromium-nickel steel Allegheny Metal. These two classes of chromium steels differ from one another both chemically and physically. The ordinary chromium steels contain only a trace of nickel and are martensitic in structure. They are air-hardening above their critical temperature and decidedly magnetic. Allegheny Metal, the chromium-nickel steel, on the other hand, contains from 7 to 10 per cent nickel in addition to 17 to 20 per cent chromium. It is fully austenitic in structure, being non-hardening at any temperature and in addition, non-magnetic. Since our results with Allegheny Metal have already been given, the discussion here will be confined to the ordinary chromium steels, Ascoloy and Enduro.

Ascoloy and Enduro closely followed or were equal to Allegheny Metal in most cases, as far as visible corrosion and loss in weight are concerned. This was true for sweet and sour milks and creams, also for neutralized cream and for most of the organic acids. In hydrochloric acid and sulphuric acid both Ascoloy and Enduro corroded very profusely, lost greatly in weight, and dropped to the bottom of the list, together with zinc and iron. This suggests that when these ordinary chromium steels begin to yield to corrosion they may become very intensely affected, corroding and pitting rapidly. As will be shown in a later article, these ordinary chromium steels also suffered some corrosion under brine treatment. Furthermore, in high-acid milk, such as acidophilus milk, both Ascoloy and Enduro produced a slight metallic flavor. Whenever these two alloys suffered corrosion the Enduro proved slightly more resistant than the Ascoloy. This was probably due to the higher chromium content of Enduro, the latter containing approximately 16.5 to 18.5 per cent chromium and Ascoloy approximately 12 to 16 per cent. It was also

noted in the case of Enduro, that the highly polished surface resisted corrosion considerably better than the unpolished back side. Similar findings are also reported by Quam (16), who found Allegheny Metal far superior to the ordinary chromium steels, and Burrell (29) who stated that "our experience with Uloy Enduro and other alloys containing Chromium, 13 to 16 per cent, but no nickel, was not satisfactory excepting in certain cases, that is, where the metal was thoroughly cleaned each day."

If one considers only the results obtained with the dairy products in this experiment, the ordinary chromium steels proved equally resistant to corrosion as Allegheny Metal, with the possible exception of metallic flavor in the high-acid acidophilus milk. However, if cognizance is taken of the extraordinarily heavy losses suffered in the weak mineral acids as shown in table 1, and the rusting in brine treatment as will be reported later, and also the metallic flavor observed in acidophilus milk, it appears that these ordinary chromium steels cannot be considered sufficiently dependable for all around use in dairy equipment on the basis of our present rather limited knowledge.

Copper, nickel silver, and Monel Metal. The metals of this group are similar in that they all contain copper which has proved undesirable for surfaces exposed to milk products.

As might be expected, copper showed itself the most objectionable of these three metals. In every milk product, tables 6 and 7, copper invariably yielded a pronounced metallic or related off-flavor. The effect on flavor here is augmented by the fact that the salts of copper themselves have an intense, puckery, metallic, bitter taste, which follows them in the dairy product. In fact, as Donauer (17) demonstrated, the intensity of metallic flavor of copper lactates is so great that less copper is required in solution to give the dairy product a metallic taste than is the case with any other metal he studied. Some of the metals with which Donauer experimented and the parts per million required to give a metallic taste are copper 4, nickel silver 5, aluminum 9, Monel Metal 10, iron 15, zinc 17, tin 50.

The visible corrosion on the copper strips, both in the weak organic acid solutions and in all the milk products, tables 2 and 5,

was very pronounced and the loss in weight, tables 1, 4, and 7, comparatively high. Even in sweet milk and sweet cream the submerged part of the strips invariably became very bright, indicating corrosion and solution, and the portion above the liquid acquired a dark tarnish.

Similar brightening and tarnishing of copper in such dairy equipment as copper vacuum pans, hot wells, imperfectly tinned copper milk coolers and vats are common occurrences and often lead to serious flavor defects in the products of plants using such equipment. Thus Supplee (18) shows that milk heated or held in contact with metallic copper takes up the metal in amounts varying from less than 1 part per million to as high as 7.4 parts per million parts of milk. Supplee and Bellis (19) reported that the copper content of milk may be measureably increased by heating or storing milk in the presence of copper, or running the milk through poorly tinned copper pipes. Rice and Miscall (20) found that copper corroded with an oxide yields much more of the metal to the milk than smooth, bright copper. Hunziker (21) states that condensed milk often takes on a metallic flavor because of its contamination with copper from the vacuum pans. Recent work by Mattick (22) showed that an oily flavor in milk was very common in England and Scotland and he attributed this defect to extremely minute quantities of copper absorbed into the milk during cooling of the milk by the use of imperfectly tinned copper coolers. Grindrod (6) reports that the sterilization of milk and evaporated milk in an apparatus made of copper causes so great damage to the milk that his process of impact sterilization is not successful with an apparatus constructed of that metal.

The damaging effect on the milk product is further augmented by the fact that the presence in it of even very minute amounts of copper salts is capable of producing most intense progressive flavor deterioration in the dairy product with age, due to oxidation and catalytic changes, as shown by earlier work of Rogers, et al. (23) and Hunziker (24) in connection with the keeping quality of butter and by Supplee (18) as related to the keeping quality of milk powder.

Of the two copper alloys, nickel silver and Monel Metal, the former proved considerably more damaging to the milk product than the Monel Metal. Thus, nickel silver produced a metallic flavor in six of the milk products, while Monel Metal yielded this defect in only two cases. As shown in tables 6 and 7, with nickel silver the metallic flavor appeared in sweet milk, sweet and sour cream heated to 145°F., acidophilus milk, butter culture, and in one batch of neutralized cream. Likewise, the visible corrosion on the metal strips held in the milk products was much greater and the loss in weight larger for nickel silver than for Monel Metal. Both alloys suffered objectionable tarnishing in almost every case, but here again the action was decidedly more pronounced with the nickel silver than with Monel Metal. It was especially noticeable that this tarnish assumed a brass-like, reddish yellow color, suggesting oxidation of the copper rather than of the nickel. It appears that when the copper alloys yield to attack it is usually chiefly the copper that goes into solution. Thus the Research Laboratories of the Sheffield Farms (25) report that "milk treated with a piece of German silver (copper-zinc-nickel alloy) at 140°F. for six hours showed the presence of copper with traces of zinc and nickel." Seligman (1) found that "when attack does take place (meaning attack of German silver or nickel silver) it is mainly copper which passes into solution." These observations bear out our findings which showed that copper had passed into solution in the milk product exposed to nickel silver and Monel Metal, respectively.

In considering the suitability of these copper alloys for dairy equipment it should be emphasized that these alloys gave evidence of considerably greater resistance to corrosion than copper. This is especially true of Monel Metal and to a lesser extent of nickel silver. Their immediate damaging effect on the flavor of the dairy product also was distinctly less pronounced but appeared in several instances. Nickel silver caused metallic flavor more often than Monel Metal. On the basis of these findings the conclusion is inevitable that neither of these alloys gives dependable protection against metallic injury to the flavor of milk products. Their use should be confined to similar limitations

as copper. These deductions are fully supported by commercial experience which, as shown by Burrell, Cornell, Hunziker, Hunziker and Hosman, and others, who demonstrated that these copper alloys in milk pails, vats, coolers, and similar equipment do, under certain conditions, cause serious flavor defects in the dairy product and can, therefore, not be recommended for use in milk work.

Aside from the damaging effect of copper salts on flavor and keeping quality of the milk product, the presence of such salts has been shown to be a menace to health. It is, therefore, pertinent to point out that the use of vacuum pans, hot wells, forewarmers, holding vats, pasteurizers, and similar equipment constructed in part or wholly of copper, or copper alloys, is highly undesirable, and yet much of the equipment used in present-day milk products plants daily exposes the product to these metal surfaces.

Iron, galvanized iron, tinned iron, and zinc. Iron proved itself most disastrous to the flavor of the milk products of any of the metals studied. As shown in tables 6 and 7 iron produced a most pronounced metallic flavor in all milk products and in many instances it appeared to cause intense putrefactive decomposition accompanied by foul flavor and odor. Similar results are also reported by Quam (26) who found that iron caused greater decomposition than any other metal. Likewise, the visible corrosion, tables 2 and 5, was most severe, both in the weak organic acids and in all the milk products; and the loss of weight, tables 1, 4, and 7, exceeded that of all other metals. In some cases the portion in the liquid was corroded so greatly as to make the iron appear silver white in color. In practically all cases the iron rusted severely above the liquid. The behavior of iron was so uniformly and highly damaging as to condemn its exposure to the milk product under any and all conditions, including black iron milk pipes, black iron steam pipes used for heating milk in the hot wells with direct steam, untinned iron milk pumps, rusty tinned iron equipment, and rusty milk and cream cans, etc.

The coating of iron with zinc failed utterly to furnish depend-

able protection. The intense corrosive properties of the zinc itself forfeit the resistance expected of the galvanized iron. While zinc produced metallic flavor in the sour milks and creams and in sour neutralized cream only, the galvanized iron caused metallic flavor in all milk products. In the case of both zinc and galvanized iron, the metallic flavor was sometimes accompanied by a sweetish taste and a marked reduction in acidity. Thus, in acidophilus milk, for instance, the acidity reached only 1.13 per cent whereas with the other metals it rose to about 1.76 per cent. In the case of galvanized iron, some of the milk products developed a fishy and bitter flavor as well.

The visible corrosion was very marked on both the zinc and the galvanized iron; the latter also showed marked rusting. The loss of weight of zinc in the dilute organic acids and the milk products averaged only about one-third of that of the iron, while the galvanized iron lost much more than did iron in the weak organic acids and equally as much as iron in the milk products. These findings are supported also by the work of Von K. Vas (27) who experimented with galvanized iron in sweet and sour whey and found that when exposed for only a few hours in the sweet whey the amount of zinc dissolved was very small, but in sour whey it amounted to 0.16 to 0.2 mgm. per square centimeter, which he considers condemns galvanized iron for use in the construction of whey tanks from the health standpoint.

It is evident from the above results that galvanized iron is exceedingly destructive to the flavor of milk products. This, together with the known toxic properties of zinc salts when present in large quantities, condemns the use of galvanized iron in any form of dairy equipment, such as milking pails, milk and cream pipes, buttermilk and whey tanks, etc.

The tinned iron proved far superior to either galvanized iron or iron. Yet in the majority of the milk products it produced a pronounced metallic flavor. The visible corrosion was considerable and, on many of the strips iron rust appeared through the tin. The loss in weight also averaged second only to iron, galvanized iron, and zinc, but in many cases exceeded that of even copper. While a heavy and uniform coating of tin does

give satisfactory protection against corrosion of the iron, such perfection of tin coating on iron is very rare. Moreover, the tin coating is porous, inviting access of the media to the easily corroded iron underneath. This provides corrosion centers on which action is concentrated and from which corrosion spreads rapidly. The damage is further aggravated by the use of strong caustic alkalies for washing purposes, which readily attack the tin, as will be shown in a succeeding article. As a convincing example of this fact may be cited commercial experience in the washing of farmers' milk and cream cans with solutions of caustic alkalies. Such cans lose their tin coating rapidly, rust profusely, and soon are in a bad and insanitary condition. It is well known, though not fully appreciated, that such cans are responsible for a great deal of the metallic flavor in cream that arrives in American creameries. There is no question that the factor of rusty cream cans plays a very important rôle in the production of cream of poor quality.

Combinations of metals. The presence of two or more metals in the same piece of dairy equipment is fundamentally undesirable. Most metals used may differ in their electrical potentials and this in turn invites corrosion by electrolysis. For similar reasons, impurities in metals are equally objectionable, as was pointed out in the case of cast aluminum. The corrosion-inciting effect of contact with other metals in the case of aluminum and chromium steel equipment, has already been explained under the respective headings of these metals.

Certain alloys have proved unsuitable for milk work because they, too, provide the elements for electrical couples. This appears to be especially the case with copper alloys, such as nickel silver, and to a lesser extent Monel Metal. When these alloys corrode the metal that goes in solution is usually found to be the copper. It is well known by the metallurgist that in the case of nickel silver, for instance, segregation may take place during the cooling of the molten alloy, thus resulting in the formation of electrical couples which, when submerged in the milk product, may incite electrolysis. The same situation prevails in equipment consisting of metal-coated surfaces, such as

tinned iron, galvanized iron, tinned copper, whenever these coatings become defective, and cause exposure of the metal underneath the coating.

Our experiments on the effect of combination of metals consisted of using strips of Allegheny Metal, Ascoloy, Enduro, nickel, and tin, which had fastened through the center of the strips rivets of the following metals: brass, copper, iron, Monel Metal, nickel, nickel silver, tin, aluminum, and solder. These strips were then totally immersed in various media, such as lactic acid, sour cream, sweet milk, etc.

The aluminum rivets showed marked corrosion and pitting in the acid products, such as in lactic acid and sour cream, except in case of the tin strip in which neither rivet nor strip was affected. In the case of the nickel strip the nickel appeared not to be affected while it tarnished in all other instances, but the aluminum rivet was much corroded. The two ordinary chromium steels were quite corroded over a considerable area around the aluminum rivet. Ascoloy was corroded the most and Enduro next. Allegheny Metal was unaffected by this aluminum rivet combination.

The iron rivets were badly rusted in all cases except the rivet in the tin strip. In the case of lactic acid all three chromium steels were corroded and markedly tarnished but the Allegheny Metal was least affected.

The tin rivets also caused the three chromium steels to tarnish and corrode severely, less so, however, than did the iron rivets. The Allegheny Metal here, too, was least affected. All other combinations of metals and rivets gave results practically identical to those obtained with the metal strips alone.

It appears from the above, therefore, that combinations of the chromium steels with aluminum, tin, or iron may prove quite disastrous to the chromium steels, causing them to tarnish and corrode markedly. Aluminum appears to have an inhibiting effect on the tarnishing of nickel but the aluminum itself is considerably affected, while in the aluminum-tin combination neither metal showed attack.

The complications involved in these tests with combinations of metals so greatly limited the scope of this part of the experiment

that the results are inadequate to draw more comprehensive conclusions. However, they may serve to show the importance of avoiding multiplicity of such metals in one and the same piece of equipment, of confining the construction of mechanical accessories and fittings that come in contact with the milk, as completely as possible to the metal of which the milk side of the equipment consists, or if different metals must be used, of giving preference to metals of similar electrical potentials.

While, for above reasons, the presence of more than one metal immersed in the milk product is undesirable, there are instances, as noted above, when the introduction of a second metal may not only be harmless, but may actually be beneficial in that it may assist in retarding corrosion of the metal it is desired to protect. Thus Quam (16) also points out that aluminum, manganese, zinc, and wrought iron materially retard the corrosion of nickel and tin. Burrell (5) and McKay (28) likewise report that aluminum noticeably prevents the discoloration and pitting of nickel. In these cases galvanic action is utilized to protect the other metal against attack.

CORROSION AT THE AIR-LIQUID LINE

It is well recognized by students of the subject of metallic corrosion, that the amount of dissolved oxygen present in a solution influences to a very marked degree the extent and type of corrosion that any given metal will suffer when immersed in the liquid. In the present experiment the air-liquid line furnished convincing evidence of the fact that often the most intense action will take place at points where the liquid is most freely exposed to the air. This was true both in the weak organic acid solutions and in the milk products. In some instances the corrosion was so great as to result in a deep cut at the air-liquid line. In the weak organic acid solutions the corrosion at the air-liquid line was most pronounced in the case of iron, galvanized iron, tinned iron, zinc, copper, nickel silver, and Monel Metal. It was less intense but distinctly noticeable on nickel, tin, tinned copper, and the aluminum products, very slight on the ordinary chromium steels, Ascoloy and Enduro, and entirely absent on

Allegheny Metal. In the milk products the corrosion at the air-liquid line was greatest in the case of iron, galvanized iron, zinc, copper, and nickel silver, less pronounced but still noticeable in many instances on nickel, Monel Metal, tinned iron, and tinned copper, and practically completely absent on tin, the aluminum products, and the chromium steels.

In acid liquids and at the higher temperatures the action near the surface of the liquid was usually greater than in the sweet products and at ordinary temperatures, although marked corrosion at the air-liquid line of some of the metals was also noticeable in the sweet milk and cream at ordinary temperatures.

These findings are in harmony with experience in commercial plant operation which involves many instances where exposure of the wet metal surface in dairy equipment to air occurs and where at such points of contact corrosion and tarnishing of the metal is more intense than where the metal is completely submerged. As striking examples here may be mentioned the blackening and spotting of tinned copper at the air-liquid line in coil cream vats and on the revolving coils themselves, the rapidity with which surface tube coolers show severe tarnishing, the rapid rusting of milk and cream shipping cans that are returned to the farms in wet condition, the ready tarnishing of copper forewarmers and vacuum pans, the intense corrosion of steel-jacketed tanks, where the jacket is emptied but remains wet after each day's operation. The action is usually further augmented in equipment exposed to direct sunlight.

Toxicity of metals. The present experiment did not include the toxicological aspect of metals. Furthermore, the scarcity of comparable and tangible data available renders a discussion of this subject difficult. There appears to be no established standard of toxicity on the basis of which the several metals herein considered may be compared with reasonable accuracy. Since it is generally conceded, however, that salts of such metals as chromium, copper, zinc, and tin, are highly poisonous, it appears expedient to emphasize here that the solubility of these metals in milk work may be a factor of considerable importance, and that the use in dairy equipment of such metals of which large

amounts go into solution, may be considered a questionable practice. This would apply to their direct physiological effect on the human system as well as to their inactivating influence on the valuable milk vitamins.

SUMMARY AND CONCLUSIONS

This experiment involves a study of the various metals used in dairy equipment. The action on the metals of weak organic and mineral acids and of sweet and sour milks and creams, and the effect of the metals on the flavor of the milk products were observed.

The metals used included aluminum and aluminum alloys, copper, nickel and copper alloys, iron, zinc, and galvanized iron, tin, tinned copper and tinned iron, two ordinary chromium steels and one chromium-nickel steel. The liquids used consisted of 1 per cent solutions of the following acids: hydrochloric, sulphuric, acetic, butyric, and lactic, and 0.2 per cent solutions of citric; and of the following milk products: sweet milk, acidophilus milk, butter culture, and buttermilk, sweet and sour cream, and sour neutralized cream. The metal strips were immersed half way in the liquids and the periods and temperatures of exposure were five days at 70°F. and five hours at 145°F.

In general, the corrosive effect on the metal was greater in the acid solutions than in the milk products. This was evident even where the acidity of the milk product was equal to or greater than that of the acid solution. This suggests that the acidity is the chief factor in metallic corrosion and that some of the non-acid milk constituents apparently exert a corrosion-protective action.

With minor exceptions, the corrosion was more intense in the high-acid products than in the low acid products and at high temperatures than at room temperature. But even in the sweet milk products and at room temperature corrosion was by no means absent.

Generally those metals that showed definite corrosion also had the most damaging effect on the flavor of the milk product. This refers particularly to iron, galvanized iron, copper, zinc, tinned iron, and nickel silver, the first three of which produced a

marked metallic flavor in all milk products and the last three in the majority of cases.

Allegheny Metal, tin, and properly tinned copper produced no damaging flavor effect whatever. These were closely followed by the aluminum products, nickel, Monel Metal, and the ordinary chromium steels. The latter group of metals, however, were not entirely negative and did produce a metallic flavor in some instances.

The accurate placement of these metals on the basis of the results here recorded according to their suitability for use in dairy equipment is difficult. Some of the metals, while harmless in dairy products of low or moderate acidity, showed a marked tendency to impair the flavor in the high-acid products. Others, while practically harmless in most of the dairy products showed lack of resistance to corrosion under certain severe conditions and, therefore, are not sufficiently dependable to be recommended for general use.

While the effect on the flavor of the milk product must ever be considered of paramount importance, a consistent classification of these metals must, in addition, take into consideration their dependability to stand up under a great variety of conditions, such as are encountered in commercial plant operation, which includes also resistance to steam, washing solutions, and cooling brines, etc. With these numerous aspects in mind the following alignment according to relative merit appears justifiable:

1. Allegheny Metal, tin, and heavily tinned copper.
   These metals have no effect on flavor and show maximum resistance to corrosion and tarnishing. The tin coating on copper must be heavy and intact.
2. Nickel, aluminum, and manganese aluminum alloy.
   These metals are not entirely satisfactory in high acid milk products. Furthermore, the nickel tarnishes readily and the aluminum is sensitive to alkali washing powders.
3. Monel Metal, Enduro, Ascoloy, and nickel silver.
   Monel Metal tarnishes appreciably in milk products. In these tests it had only slight effect on flavor. Enduro and Ascoloy are sensitive to high-acid products and their performance in

dairy equipment is uncertain. Nickel silver tarnishes severely and was injurious to flavor in the majority of milk products.

4. Tinned iron, copper, galvanized iron, iron, and zinc.

With the exception of properly tinned iron, this group is unfit for use in contact with milk products. Tinned iron is equally so whenever iron is exposed.

ACKNOWLEDGMENTS

We are greatly indebted to the Allegheny Steel Company, the Aluminum Company of America, D. H. Burrell & Company, J. G. Cherry Company, The Creamery Package Manufacturing Company, The International Nickel Company, and the Jensen Creamery Machinery Company, for materials and data generously placed at our disposition.

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THE BACTERIAL COUNT OF ICE CREAM HELD AT FREEZING TEMPERATURES*

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During the course of an earlier investigation on ice cream (1), it was observed that the total counts of bacteria in samples received from retailers were much higher than in those received from producers. It is generally assumed that a freezing temperature inhibits the growth of bacteria. If this assumption is true, then the increased counts found in the retailers' samples would seem to be due to insanitary methods. However, the increase in numbers was of such a magnitude as to render this simple explanation questionable. It occurred to us that it might be helpful to investigate this problem and to determine, if possible, the cause of the increase noted. In this investigation we determined the effect of low temperatures upon the bacterial count of ice cream.

REVIEW OF LITERATURE

A review of the available literature casts considerable doubt upon the ability of freezing temperatures to completely inhibit bacterial multiplication in ice cream. Fabian (2) states that in most cases when ice cream is held at low temperatures, there is usually a slight decrease for two to four days, then an increase for ten days, after which there is a gradual decrease, and finally a fall below the original count. Stiles and Pennington (3) made counts of four samples over a period of thirty-four days. The counts increased slightly to the fourth day, then decreased to the fourteenth day when a marked increase occurred followed by a sharp decline after the twenty-seventh day. Similar findings were reported by Ellenberger (4).

* Received for publication October 24, 1928.

On the other hand, Tracy and Peterson (5) kept ice cream mix at 32° to 35°F. for a period of thirty-two days, but found no marked increase in numbers of bacteria until after the fourteenth day. Hammer (6) did not find any tendency of the bacteria to increase in numbers during the storage of ice cream. Esten and Mason (7) studied twelve samples of ice cream over a period of two months, but found no consistent increase or decrease. Hammer and Goss (8) examined 51 samples of ice cream of which 39 were packed in salt and ice, and 12 were stored in the hardening room. They found that during proper storage there is no increase and there may be a decrease in the number of bacteria present. Fay (9), Palmer (10), and Rettger (11) found that if ice cream was held at a suitable temperature, there was a material drop from time to time in the viable bacteria present. According to Fabian and Cromley (12) storing the product at −20.5°C. for ten to twenty-one days decreases the plate count in the majority of cases, but freezing with brine at an average temperature of −14°C. permits bacterial multiplication.

The varying temperatures employed by the different workers leaves some doubt as to what actually occurs during cold storage, but in a general way, they seem to indicate that storing at temperatures above −14°C. did not completely inhibit bacterial multiplication.

METHODS EMPLOYED

Source of samples. The ice cream came from two wholesale makers and it was delivered to the laboratory soon after freezing. The samples were then placed at the desired temperature for thirty days, bacterial counts being made every other day.

Method of analyzing. Portions of the ice cream were removed to sterile petri dishes, placed in the incubator at 37°C. for ten minutes to liquefy, and then serial dilutions up to 1:1,000,000 were made. One cubic centimeter portions were plated with standard beef extract agar. Triplicate plates were made from each dilution, incubated for forty-eight hours at 37°C. and the colonies counted. Only the plates showing between 50 and 300 colonies were counted and averaged for the final figures.

Method of storage. The ice cream was stored in the freezing compartment of a Frigidaire cooler, the temperature of which was carefully checked. Twelve samples were stored at −3°C., 12 at −6°C., and 9 at −10°C. The temperatures remained constant during the experiment.

RESULTS OBTAINED

At −3°C. The samples were purchased in lots of four each from a single maker "X." Table 1 gives the results for each sample of the first lot. Since the four samples came from a single batch of ice cream, they do not differ greatly.

TABLE 1

Giving bacterial counts (in millions per gram) of four samples of ice cream held at −3°C. for thirty days

DAYS STORED	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4
1	26.1	31.0	29.0	28.9
3	31.2	30.0	29.8	34.0
5	32.0	35.0	32.0	40.0
7	74.0	57.0	58.0	81.0
9	121.0	118.0	108.0	133.0
11	137.0	132.0	129.0	151.0
13	149.0	144.0	151.0	163.0
15	191.0	197.0	241.0	257.0
17	184.0	176.0	192.0	201.0
19	161.0	158.0	174.0	169.0
21	122.0	133.0	145.0	139.0
23	99.0	104.0	112.0	121.0
25	76.0	89.0	93.0	89.0
27	65.0	67.0	63.0	76.0
29	44.0	52.0	45.0	51.0

The table shows that the four samples of ice cream had approximately the same number of bacteria at the same time during the experiment, and the number remained practically constant during the first five days of storage, then increased rapidly to the fifteenth day, when a more gradual decline set in.

Since the subsequent lots were handled like the first it scarcely seems worth while to give all the detailed figures as determined;

instead, only the average of the lot of four samples will be given. Table 2 gives the averages of all the lots held at −3°C.

The averages all show the same trend as do the results of the specific samples, namely, the first five days at −3°C. shows a comparative quiescence with only a slight increase, then a fairly rapid increase for ten days, followed by a decline which was quite rapid at first, then proceeded more slowly.

At −6°C. The samples stored at −6°C. were 12 in number, all from a single producer, "Y." They were divided in two lots

TABLE 2

Giving averaged bacterial counts (in millions per gram) for each lot of four samples held at −3°C.

DAYS STORED	LOT I (SAMPLES 1, 2, 3, 4)	LOT II (SAMPLES 5, 6, 7, 8)	LOT III (SAMPLES 9, 10, 11, 12)
1	29.0	36.3	37.0
3	31.0	37.5	39.3
5	34.8	50.5	42.8
7	70.0	70.8	74.3
9	120.0	117.8	127.8
11	137.3	142.0	169.5
13	151.5	176.8	198.8
15	221.5	203.3	224.5
17	188.3	181.8	229.5
19	165.5	148.3	181.0
21	134.8	127.0	152.0
23	109.0	107.8	134.3
25	86.8	85.8	120.0
27	67.8	68.3	100.5
29	48.0	57.3	84.0

of six samples each. The samples had a lower initial count than those from "X." Again the counts for all the samples in each lot are averaged and the averages given in table 3.

As may be seen the results at −6°C. parallel those at −3°C. in a general way. The initial number of bacteria was very much smaller than in the samples from "X," and these numbers always remained relatively small, but the maximum occurred again about the fifteenth day. The counts at the end of the period of storage were lower, however, than the initial counts, tending to show increased inhibition due to increased cold.

TABLE 3

Giving averaged bacterial counts (in millions per gram) for each lot of six samples of ice cream held at −6°C. for 30 days

DAYS STORED	LOT IV (SAMPLES 13, 14, 15, 16, 17, 18)	LOT V (SAMPLES 19, 20, 21, 22, 23, 24)
1	0.7	1.3
3	0.8	1.4
5	1.0	1.3
7	1.1	1.3
9	1.3	1.4
11	1.5	1.6
13	1.6	1.7
15	1.8	2.1
17	1.5	1.9
19	1.3	1.7
21	1.1	1.6
23	0.9	1.3
25	0.8	1.0
27	0.5	0.9
29	0.5	0.8

TABLE 4

Giving averaged bacterial counts (in millions per gram) of two lots of ice cream held at − 10°C. for thirty days

DAYS STORED	LOT VI (SAMPLES 25, 26, 27, 28, 29)	LOT VII (SAMPLES 30, 31, 32, 33)
1	0.9	1.5
3	0.7	1.0
5	0.4	0.6
7	0.9	0.7
9	1.0	0.8
11	1.2	1.0
13	1.7	1.3
15	1.8	1.6
17	2.0	1.9
19	1.8	2.3
21	1.5	2.1
23	1.1	1.9
25	1.0	1.8
27	0.9	1.6
29	0.8	1.4

At −10°C. All the samples stored at −10°C. came from producer "Y." They were divided into two lots of 5, and 4 samples each. The averages for each lot are given in table 4.

The results at −10°C. differ from those at −3°C. and −6°C. in that there occurred an initial decrease. This decrease was followed after a number of days by an increase as in the previous samples. This increase was followed by a gradual decline.

DISCUSSION OF RESULTS

Viewing the results as a whole they seem definitely to indicate that temperatures between zero and −10°C. do not inhibit the multiplication of some of the species of bacteria found in ice cream. These findings parallel quite closely the results obtained by Fabian (2), and in a general way those of Stiles and Pennington (3), and of Ellenberger (4). They tend to show that progressive lowering of the temperature decreases the amount of multiplication and they point quite definitely to some temperature at which multiplication must cease. Doubtless some of the workers reached such low temperatures; if they did, our findings do not necessarily disagree with theirs.

The variation in results obtained by others might depend upon a variation in the bacterial flora. Our samples came from only two producers, "X" and "Y," hence may not truly represent all the possible floras. We made only a partial study of the psychrofilic flora present, and found the species belonged largely to the non-sporebearing types present in water and soil. Conceivably, if these were killed by pasteurization, there might be no multiplication of the species remaining.

We also found, as did Hammer (6), that bacteria forming gas in lactose bouillon tend to disappear during cold storage and frequently died out completely in ice cream stored for thirty days.

Our results furnish an explanation of the original question that confronted us, namely, the greatly increased numbers of bacteria found in retailers' samples of ice cream as compared with those from the makers. Obviously the refrigeration employed by retailers permits the multiplication of some of the bacteria present. Hence, it is not necessary to invoke unsanitary methods of handling to account for the numbers of bacteria, although this may still be a factor in some cases. The results are also important in the consideration of bacterial standards for ice cream. It would

seem that any standard adopted should make allowance for the increase in numbers due to holding the product. The California Standard limiting the number of bacteria per gram to 150,000 would seem to work an undue hardship on many of the retailers, if the results of Weinzirl and Harris (1) are representative of conditions in general.

SUMMARY AND CONCLUSIONS

1. Thirty-three samples or bricks of ice cream from two producers were kept at temperatures below zero centrigrade and examined for numbers of bacteria per gram on alternate days. Twelve samples were held at −3°C., 12 at −6°C., and 9 at −10°C.

2. The results indicated that storage of ice cream at −10°C. or above does not prevent all bacterial multiplication or increase in the bacterial count.

3. The results furnish at least a partial explanation of the increased numbers of bacteria found in retailers' samples as compared with those from producers.

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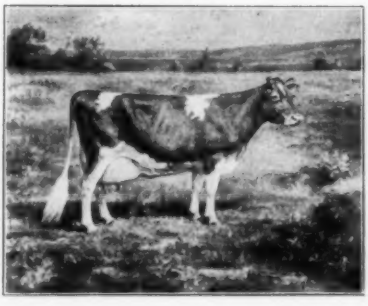

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2. Sodium hypochlorite is effective as a sterilizing agent for dairy equipment when used in proper strength.

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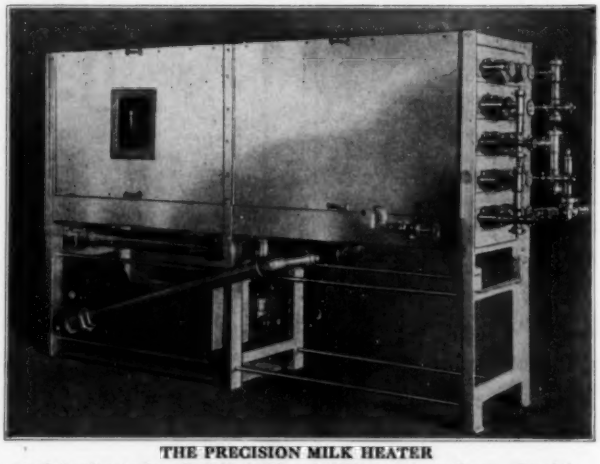

THE PRECISION MILK HEATER
Built in sizes to handle 9000, 12000 and 15000 pounds per hour. Special sizes. The heater that prevents overheating, yet heats to desired limit

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The Precision Milk Heater is adaptable to any approved type of continuous holder system. It has ample reserve capacity, making preheaters and forewarmers unnecessary.

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Above—Mojonnier Milk Tester at Hendler Creamery Co., Baltimore

At Left—Mojonnier Overrun and Weight Tester at Acme Dairy Co., Toronto

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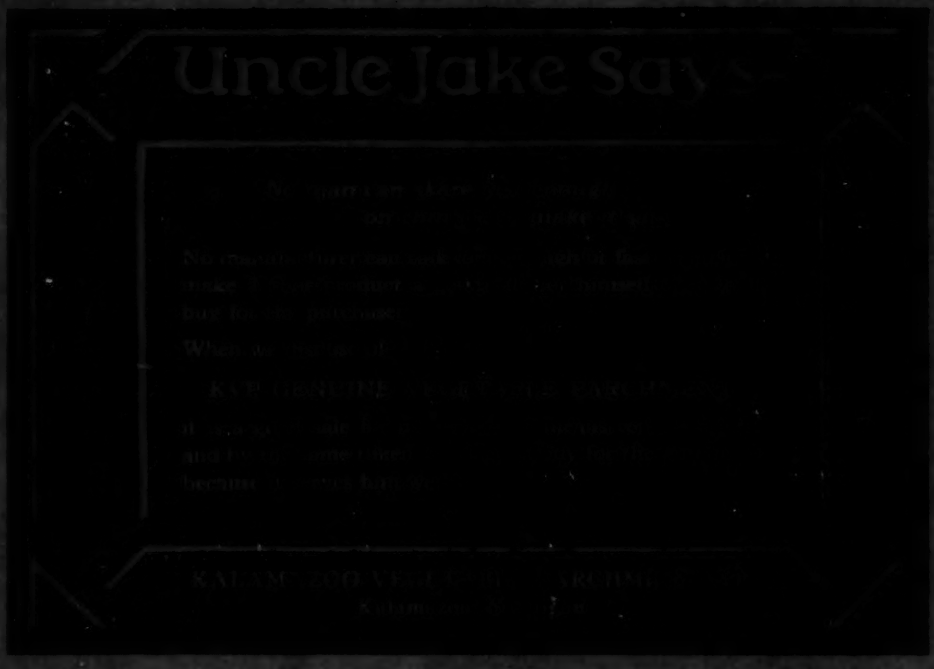

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